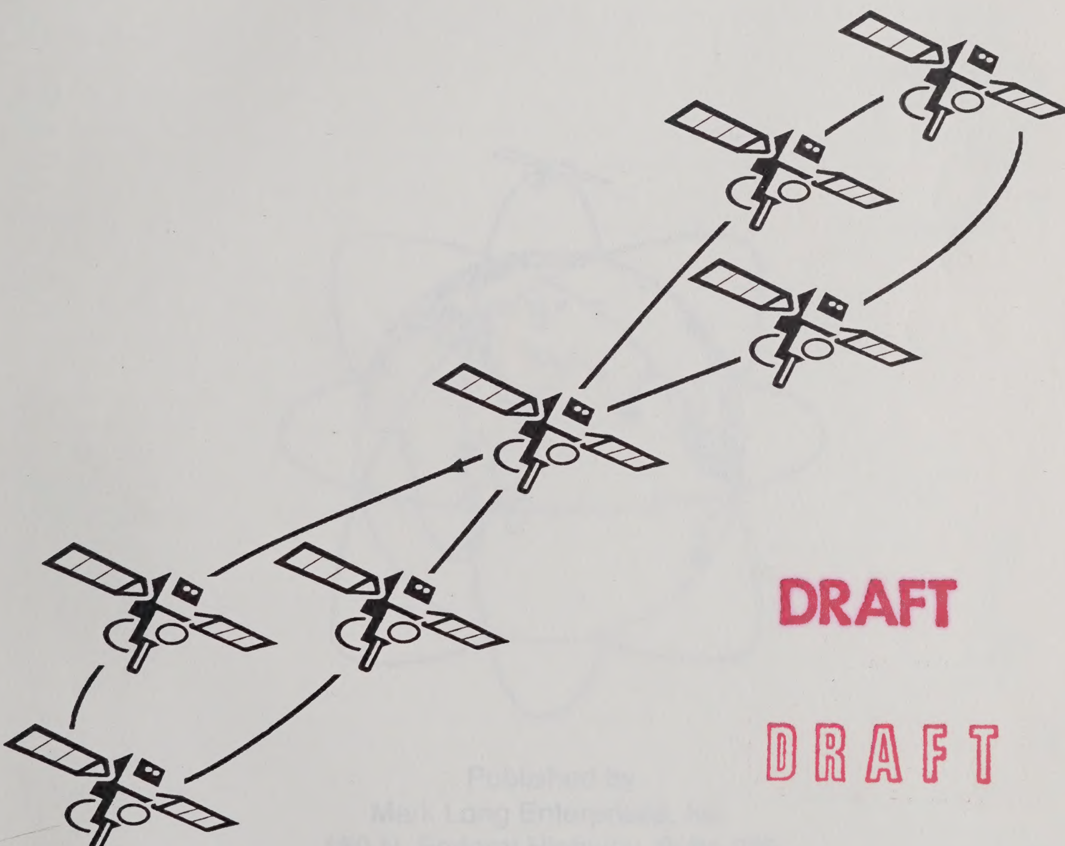
The Inclined Orbit Satellite TRACKING GUIDEBOOK

BY MARK LONG & JEFFREY KEATING

PUBLISHED BY MLE INC.

The Inclined Orbit Satellite TRACKING GUIDEBOOK

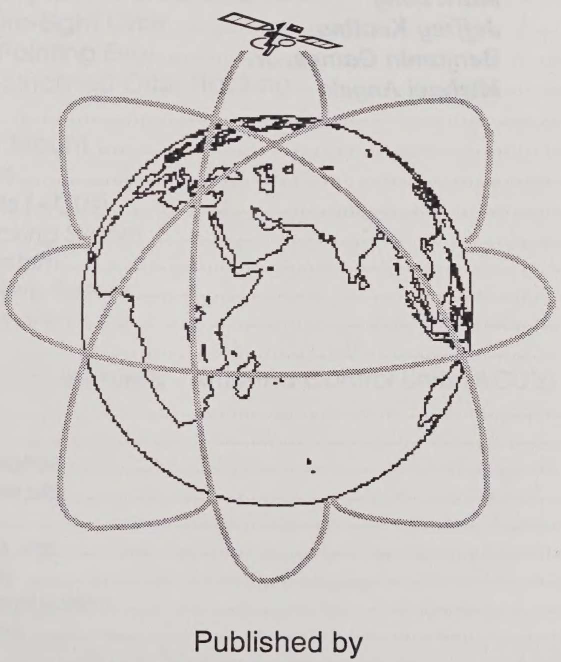


DRAFT

DRAFT

The Inclined Orbit Satellite TRACKING GUIDEBOOK

by Mark Long & Jeffrey Keating



Published by
Mark Long Enterprises, Inc.
150 N. Federal Highway, Suite 230
Ft. Lauderdale, Florida 33301

REVISED THIRD EDITION—April 3, 1993
PRINTED IN THE UNITED STATES OF AMERICA

ISBN #: 0-929548-12-4

Publisher:	*Mark Long*
Research:	*Jeffrey Keating*
Editor:	*Benjamin Gaines, Jr.*
Graphic design:	*Michael Angelo*

Table of Contents

Introduction

Satellite professionals working in the direct-to-home and cable TV markets already should be familiar with the mechanics of the geostationary orbit, an area of outer space "real estate" located some 22,300 miles above the Earth's equator. This unique orbit provides telecommunications spacecraft with the ability to remain anchored at "fixed" locations in the sky relative to receiving stations down on the ground. The end result is that the acquisition and continuous reception of geostationary satellite signals is a relatively simple and inexpensive proposition.

As satellites age, however, their ability to remain anchored at precise locations over the Earth's equator is dramatically reduced due to the limitations of their on-board stationkeeping fuel supplies. In many cases, a special maneuvering technique called an "inclined orbit" can be used to add several years of commercial operation to their design lifetimes.

Just what is an inclined orbit? As viewed from the ground, the inclined orbit satellite traces a figure-eight pattern in the sky with the satellite north of the Earth's equator for twelve hours and south of the equator for twelve hours of each twenty-four hour period. In order for satellite earth stations to continuously receive their signals, the movements of these wayward communications satellites must be continually tracked.

Today, as well as for the foreseeable future, inclined orbit satellites will play a major role in worldwide satellite telecommunications. The purpose of this guidebook is to delineate all of the underlying principles behind satellite tracking technology, including the why and how of inclined orbit satellites, inclined orbit tracking criteria, single-axis versus dual-axis motorized mounts, the monopulse, step, predictive, and program modes of tracking, and the proprietary satellite control technique known as the Comsat Maneuver.

In order to provide a comprehensive analysis of developments in the field, numerous photos, charts, and graphs are presented, along with a comprehensive listing of the manufacturers of inclined orbit tracking devices and detailed descriptions of individual products. Moreover, this indispensible handbook presents a complete list of all of the world's present and future inclined orbit satellites, their orbital position, present degree of inclination, and a four-year projection of future inclination levels.

The **Inclined Orbit Satellite Tracking Guidebook** will expand your knowledge of the field and provide you with the necessary tools for competing in the global satellite marketplace. This book also can be used in conjunction with the **World Satellite Almanac** and **World Satellite Annual** to gain a complete picture of how satellites are being used globally.

Mark Long and Jeffrey Keating
May 8, 1993

CHAPTER ONE: UNDERSTANDING ORBITAL INCLINATION

Man-made satellites can be placed along many different paths—or orbits—as they revolve about the Earth. The plane of these orbits can be equatorial, polar, or inclined. A polar orbit has a plane that is more or less parallel to the Earth's polar axis, while the plane of the geostationary orbit is equatorial in nature, lying parallel to the Earth's equator. Orbits that are offset in degrees from the Earth's equatorial plane are called "inclined orbits".

The communications satellites in geostationary orbit are located above the equator and revolve around the earth at the same rate the Earth rotates on its axis. To an observer or satellite antenna on the ground these satellites appear to be stationary. However, geostationary satellites are constantly being subjected to forces such as the gravitational attraction of the Sun and Moon, the radiation force from sunlight, and the Earth's gravitational field, all of which create a tendency for any "stationary" satellite to drift away from its assigned "subsatellite point" over the Earth's equator.

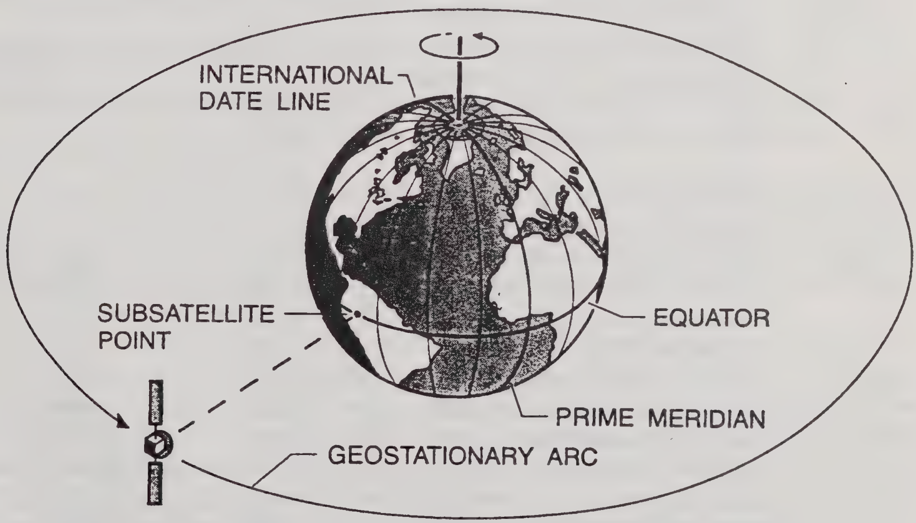


FIG. 1-1. Each geostationary communications satellite is assigned a nominal orbital location, or subsatellite point, which is located about 22,300 miles above the Earth's equator.

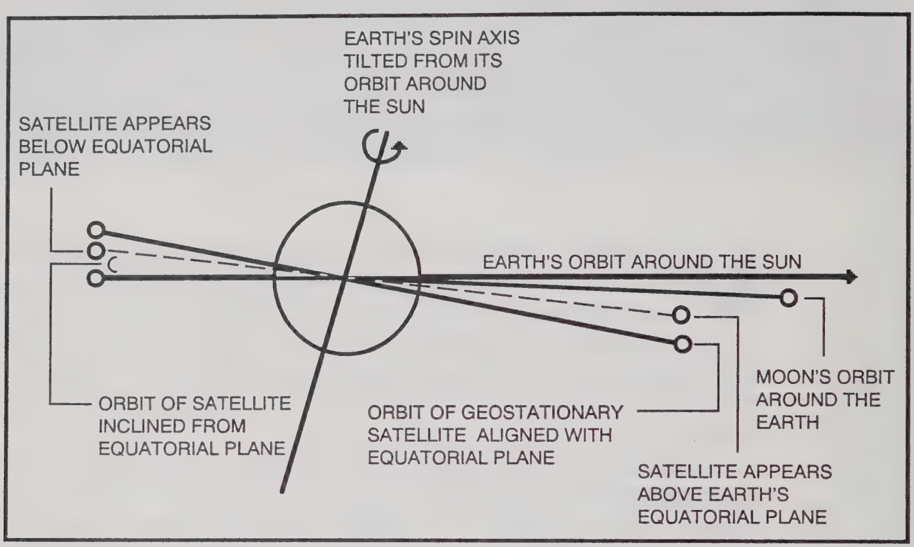


FIG. 1-2. When viewed from the side, it can be seen that for the entire day the Sun and Moon pull on the satellite in the direction to align it with their orbits. With no North/South stationkeeping, the satellite's orbit is continously pulled away from its desired orientation and becomes inclined with respect to the Earth's equatorial plane. (Concept courtesy of Sea Tel).

The satellite's momentum and the Earth's gravitational field act to keep the satellites in geosynchronous orbit—a prograde orbit having a period equal to that of the Earth's rotation but not necessarily geostationary. The gravitational attraction of the Moon and the Sun primarily affect the orbit in a North-South direction while the radiation force of sunlight and the "asymmetry" in the Earth's gravitational field primarily influence the orbit in an East-West direction.

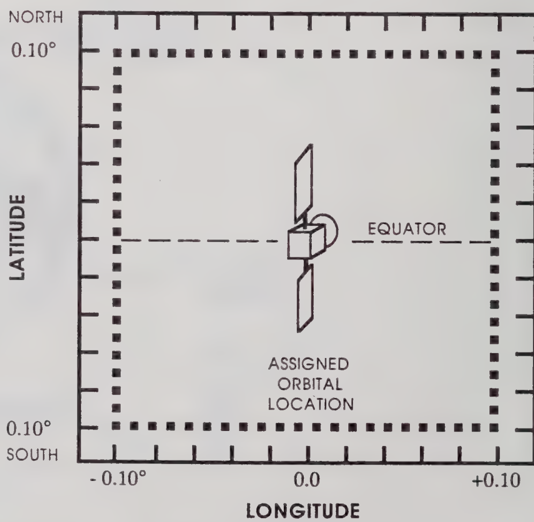


FIG. 1-3. Geostationary Stationkeeping "Box".

Under normal stationkeeping procedures, most geostationary communications satellites are allowed to wander ±0.1 degrees in the North/South direction and ±0.05 degrees in the East/West direction from their assigned longitudinal positions over

the Earth's equator. Stationkeeping fuel onboard the satellite is periodically used to keep the satellite confined to this celestial "box". These corrections are performed by firing thrusters, pushing the satellite back toward its assigned position. The maneuverability of the satellite, and thus its useful lifetime, is limited to the amount of stationkeeping fuel onboard the satellite when it reaches its assigned position and how well the expenditure of stationkeeping fuel is managed over the lifetime of the spacecraft.

If the satellite operator were to cease East-West stationkeeping, the satellite would begin to drift away from one of two natural "peaks" of orbital equilibrium located at approximately 11 degrees West Longitude and 162 degrees East Longitude and move toward the nearest of two "valleys" located at about 105 degrees West Longitude and 75 degrees East Longitude. In between each peak and valley in the geostationary arc are areas of maximum East or West influence. Satellites located near the areas of maximum influence therefore have to counteract greater forces than those located at the "valleys" of the arc.

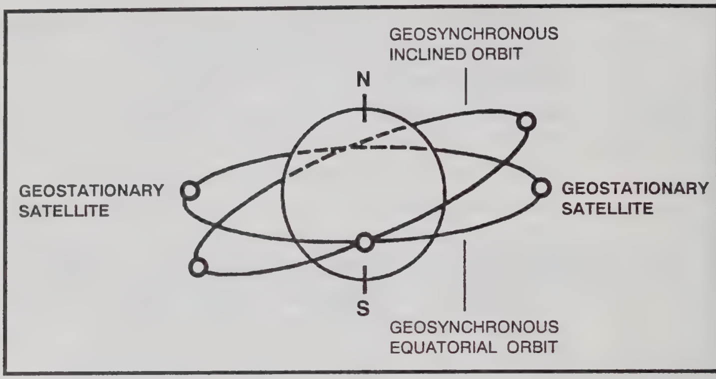
If an operational satellite were allowed to drift away from its assigned orbital position towards one of these valleys, it could cause interference to satellites positioned at other orbital locations within the geostationary arc as the drifting spacecraft passed them by. Eventually the satellite would go beyond the Earth's horizon as seen from the location of the controlling uplink site. This particular situation happened twice in 1992, when both the Arabsat 1A and 1B satellites unexpectedly ran out of East-West stationkeeping fuel and drifted Eastward toward the valley at 75 degrees East Longitude. The Arabsat consortium continued to operate the satellites as they drfited Eastward until they reached the vicinity of the Indian Ocean INTELSAT satellite cluster which ranges from 57 to 66 degrees East Longitude. As each Arabsat satellite approached the Indian Ocean INTELSAT cluster, their communications payloads were shut down to prevent interference to the INTELSAT spacecraft.

Fortunately it takes relatively little fuel to correct for East-West drift of the satellite compared to the larger amount of fuel needed to correct the North-South drift. By keeping the satellite's Longitude controlled but letting the satellite drift in Latitude (i.e., the North-South direction), the lifetime of the satellite can be greatly extended.

It is in the North-South direction—perpendicular to the direction of orbital motion about the Earth's equator—that the Sun and Moon exert their most influence. When a satellite begins to drift in the North-South direction the effect is to decircularize the orbit, forming an ellipse with an apparent daily or "diurnal" East-West motion about the assigned sub-satellite point above the equator. As luck would have it, however, the circular orbit induces a certain amount of rigidity to the elliptical motion of the spacecraft which counteracts the East-West motion to a great extent, thereby holding the ellipticity to a low level throughout the lifetime of the spacecraft.

Given an initial movement to the North of the subsatellite point, the

FIG. 1-4. Geosynchrnous equatorial versus geosynchronous inclined orbits.



spacecraft must continue to orbit the Earth's center, so that twelve hours later, the satellite will have crossed the equator heading in the South direction. The satellite moves at the fastest speed at the twice-daily equatorial crossing and slowest at the North and South apexes of the inclined orbit. The period of the North-South motion is nearly 24 hours in what is known as "sidereal time" —the equivalent of 23 hours, 56 minutes, and 4 seconds in mean solar time, allowing for the Earth's progress around the Sun during the course of one rotation.

Stationkeeping Fuel Expenditures

A good explaination of fuel consumption is detailed in Comsat's U.S. patent number 4,776,540 which states: "*.....a conventional satellite such as Comstar (Trademark), uses an average of 37 pounds of fuel for stationkeeping during each year of the latter part of its design life. Of the 37 pounds of fuel consumed in a year, approximately 34 pounds are used for north/south correction, while only 2 pounds are used for east/west correction and 1 pound for attitude control. Since such a conventional satellite is provided with approximately 340 pounds of fuel and uses more of that fuel in the earlier part of its design life, it is expected to run out of fuel in just over 7 years.*"

If North/South stationkeeping is eliminated, the fuel can then be used for East/West stationkeeping. A general rule-of-thumb here is that for every month of North/South stationkeeping fuel which is diverted to East/West stationkeeping the useful life of the satellite in an inclined orbit can be prolonged by one year.

Spin-stabilized spacecraft carry two fuel tanks with a valve between them. When the spacecraft approaches the final 12 to 18 months of its normal mission life, the valve is opened and a series of maneuvers are initiated to adjust the fuel levels in the two tanks so that they are balanced, or equal in content. The valve is then closed and the fuel is gradually consumed from only one of the tanks. Once this tank's contents is depleted, the engineers can then calculate the amount of fuel still remaining in the

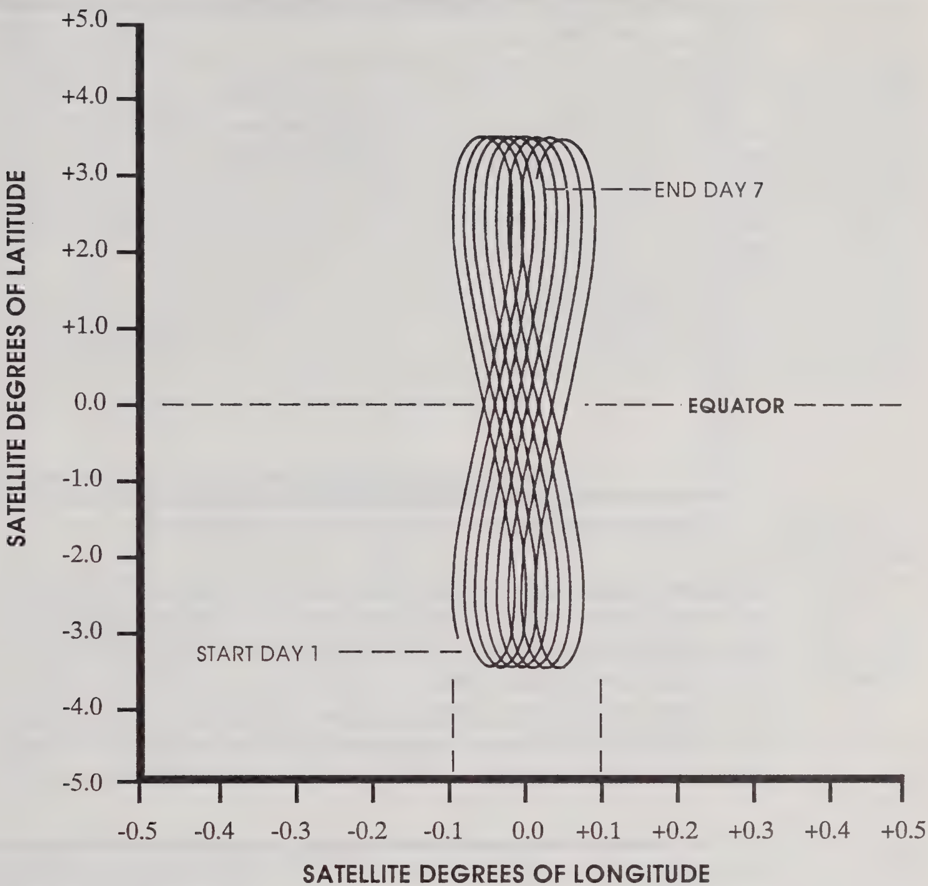


FIG. 1-5. Satellite Motion in 3.5° Inclined Orbit Over a Seven-Day Period.The above plot of a 3.5° inclined orbit satellite over a seven day period shows the degree of East/West motion which will occur. At the end of the 7-day period, the satellite operators will initiate stationkeeping commands that will reverse the direction of the East/West drift so that the satellite remains within its ±0.1°longitudinal "box". Whenever the inclined orbit exceeds 4 degrees of North/South movement, the width of the figure-eight motion will begin to exceed ±0.1 degrees.

other tank and consequently determine just how many months they can continue to perform normal geostationary operations or by how many years the useful life of the satellite can be extended by discontinuing North / South stationkeeping.

Other Limitations Governing Inclined Orbit Operations

Beyond the fuel considerations, there are other potential limiting factors governing use of the inclined orbit mode by a communications satellite. One

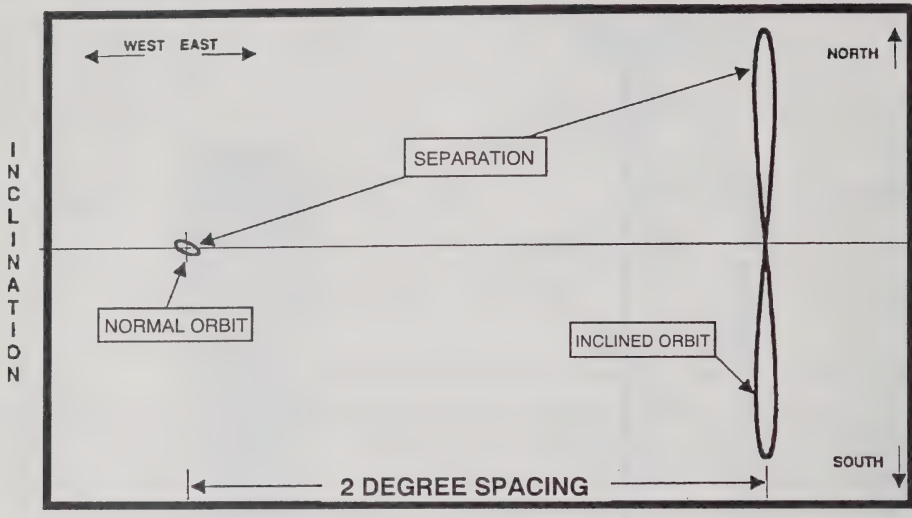


FIG. 1-6. Orbit trajectories for two geosynchronous satellites.

question that readily comes to mind is just how much of an inclination can be used without causing interference to other satellite systems or to terrestrial communications networks which share frequency spectrum with communications satellites.

In 1992, the World Administrative Radio Conference (WARC-92) met to determine world telecommunications policy for the next ten years. Operating under the auspices of the International Telecommunication Union—a

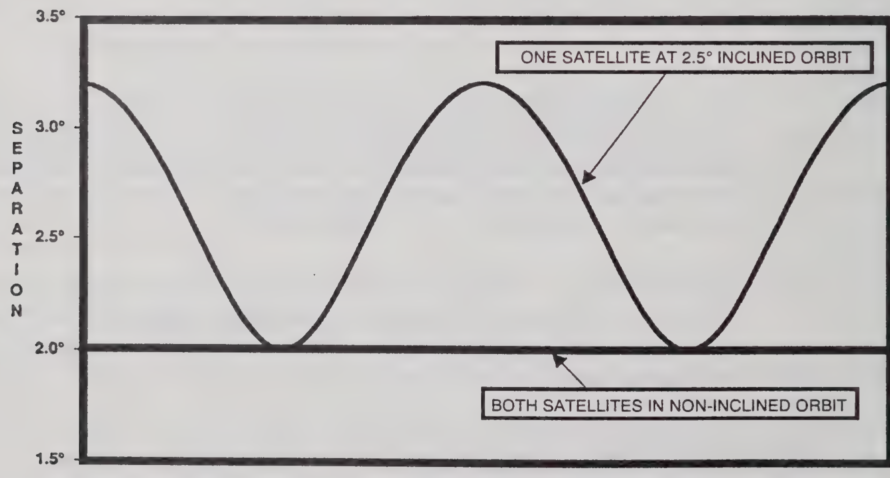


FIG.1-7. Mean separation between two adjacent 2 degree spaced satellites.

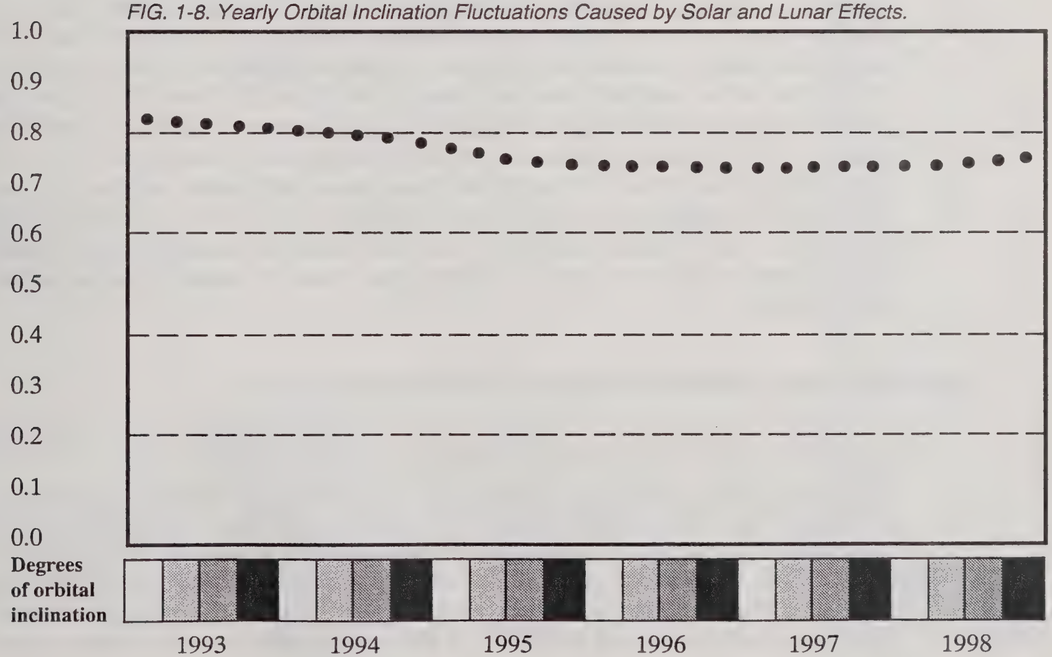
principal agency of the United Nations—WARC decisions act as treaties among nations.

WARC-92 examined the maximum allowable inclination angle of satellite networks using slightly inclined geosynchronous satellite orbits. While WARC-92 decided not to adopt any specific values of maximum inclination, the Conference noted that from a technical standpoint, in frequency bands which are not shared with terrestrial systems, geostationary satellites can operate until reaching a natural inclination limit of 15 degrees without causing significant interference to other satellite networks. However, in frequency bands shared with terrestrial systems, WARC-92 noted that the natural limit may not be acceptable and that the maximum inclination angle has yet to be clarified. In practice, satellite operators have, for the most part, elected to cease inclined orbit transmissions before a communications satellite exceeds an inclination value of ±6.0 degrees.

The Mechanics of Inclined Orbit Operations

The orbital inclination of a satellite is defined as the angle in degrees of the plane of the satellite's orbit relative to the Earth's equatorial plane. (Polar orbiting satellites have inclinations near 90 degrees taking them over the poles.) Typically the inclination of geostationary satellites is kept to less than ±0.1 degree. If North-South stationkeeping is stopped the inclination angle of the satellite will gradually increase. The annual change in inclination

FIG. 1-8. Yearly Orbital Inclination Fluctuations Caused by Solar and Lunar Effects.



varies from year to year, averaging about 0.8 degrees per year during the early 1990s. The effect changes because the angle between the plane of the Moon's orbit and the equatorial plane changes from year to year.

A large percentage of today's communications satellites are currently operating in the inclined orbit mode. (A summary chart appears on the following page and a complete list can be found in Chapter 4). The major drawback to this mode of operation is that since the satellite appears to be moving as viewed from the ground, the antennas on the ground must now track the satellite's movement.

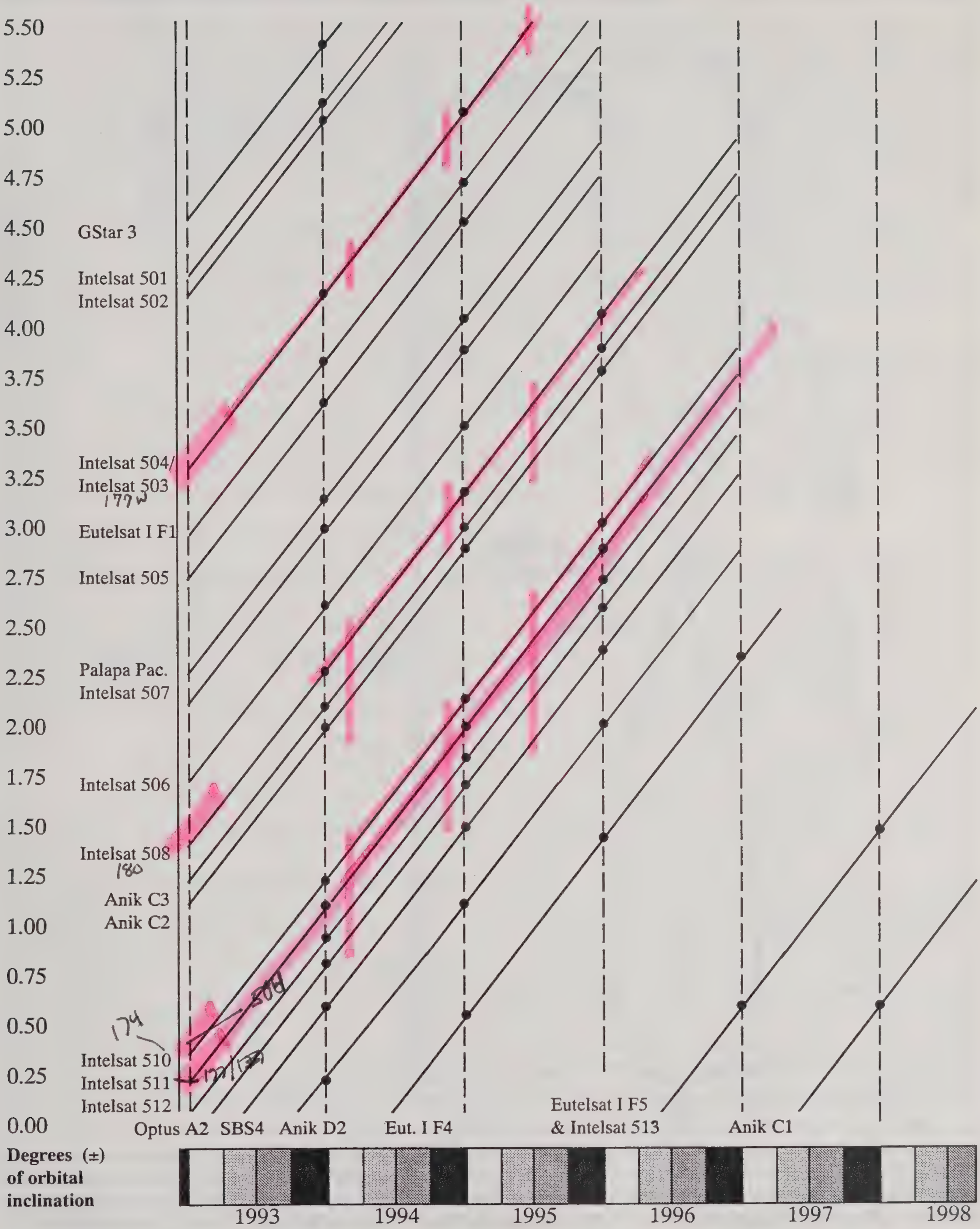
As the inclined-orbit satellite circumnavigates the Earth it exhibits a daily North-South oscillation. Even though the satellite is traveling at the rotational speed of the Earth, to an observer on the ground its position will trace a slim "figure 8" pattern in the sky over the course of each 24 hour period. At small inclinations, the pattern of satellite motion is actually a very narrow elliptical shape, appearing for all intents and purposes as a straight line. This pattern becomes more of a figure 8 as the orbital inclination of the satellite increases.

The actual shape of the figure-eight curve depends upon the value of the inclination angle, "i". In a pioneering article which first appeared in *CATJ* magazine during the early 1980s, Stephen J. Birkill presented the following description of the inclined orbit: "At the left side of this chart (on page 18) is the track of the subsatellite point for an inclination of 30 degrees. The numbers along the curve are hours from ascending node (North-bound equator crossing). By contrast, the short line at the right of the diagram is the ground track for three-degree orbital inclination, drawn to the same scale. To make it clearer, the 3 degree orbital inclination has been scaled up by a factor of ten and redrawn at center. Its width in the East-West direction is seen to be a small fraction of its North-South extent. In fact the East-West component of motion is less than ±0.04 degrees in Longitude, for i - 3°. Considering that even a 6-meter antenna has a half-power beamwidth (at 4 GHz) of 0.9 degrees, and that most domestic birds have a stationkeeping tolerance of ±0.1 degrees or better, it is clear that we can neglect the "width" of the figure eight curve for all practical purposes for small values of orbital inclination."

Inclined Orbit Satellites and the Comsat Maneuver

Geostationary satellites occupy relatively fixed points in the sky when viewed from the Earth and their footprints remain continuously directed at their respective coverage areas on the ground. The antenna pattern or "footprint "g enerated by inclined orbit satellites, however, will shift its center point from the desired coverage area to locations to the North and South. Even if all associated ground stations are able to track the drift of the satellite, the shift in the satellite's footprint causes the signal's effective isotropic radiated power or "EIRP" to fluctuate, often in a dramatic fashion.

FIG. 1-9. Estimated Orbital Inclinations for Existing Communications Satellites



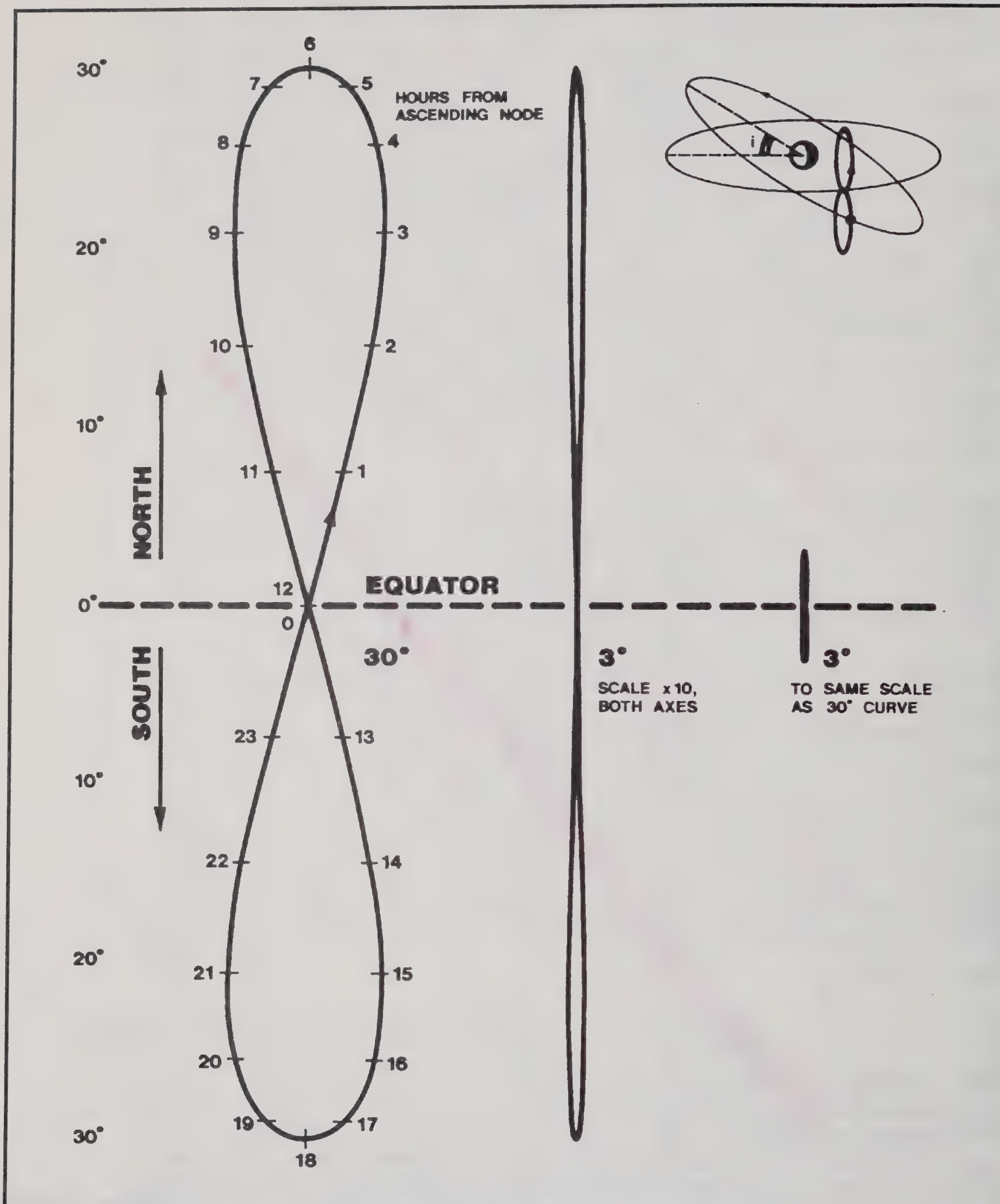


FIG. 1-10. As viewed from the ground, the inclined orbit describes a figure eight type of motion with the satellite north of the equator for twelve hours and south of it for twelve hours. The width of the figure eight is very small which, for low values of inclination, appears to be a line which lies perpendicular to the satellite arc. (Courtesy Stephen J. Birkill.)

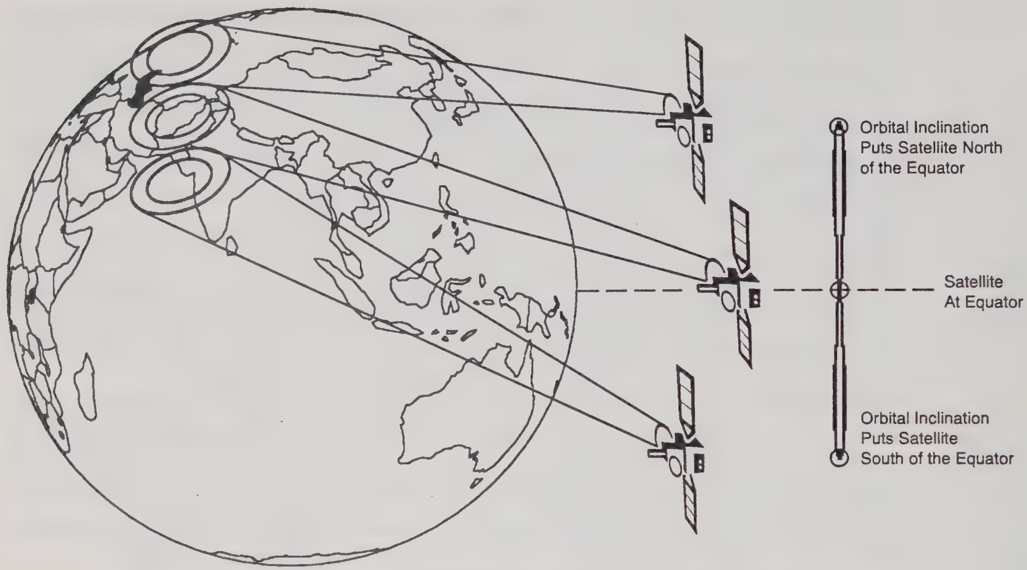
Developed by Comsat Corporation, a proprietary orbital technique called the "Comsat Maneuver" is being used by various satellite operators—including Comsat, Hughes, and Intelsat—to prevent their older spacecraft operating in an inclined orbit mode from dramatically shifting the directivity of their beams. The Comsat Maneuver consists of subtle, but precise, changes in the physical orientation or "attitude" of the satellite that are commanded by the controlling earth station. These periodic changes in orientation ensure that the antenna pattern remains centered over the desired coverage area. The satellite's North and South movements still occur, but now each network's uplink and downlink antennas can maintain relatively constant signal levels by tracking the movement of the inclined orbit satellite. Motorized antenna systems are used to alter the declination or inclination of all associated earth stations in the system.

Even when the Comsat Maneuver is used, however, there will be some fluctuation in EIRP down on the ground. The amount of variation is directly related to the extent of the satellite's orbital inclination. At high orbital inclinations, this can be a significant factor—especially for the smaller, more concentrated Ku-band satellite spot beams—and must be taken into consideration when planning the design of the satellite receiving system.

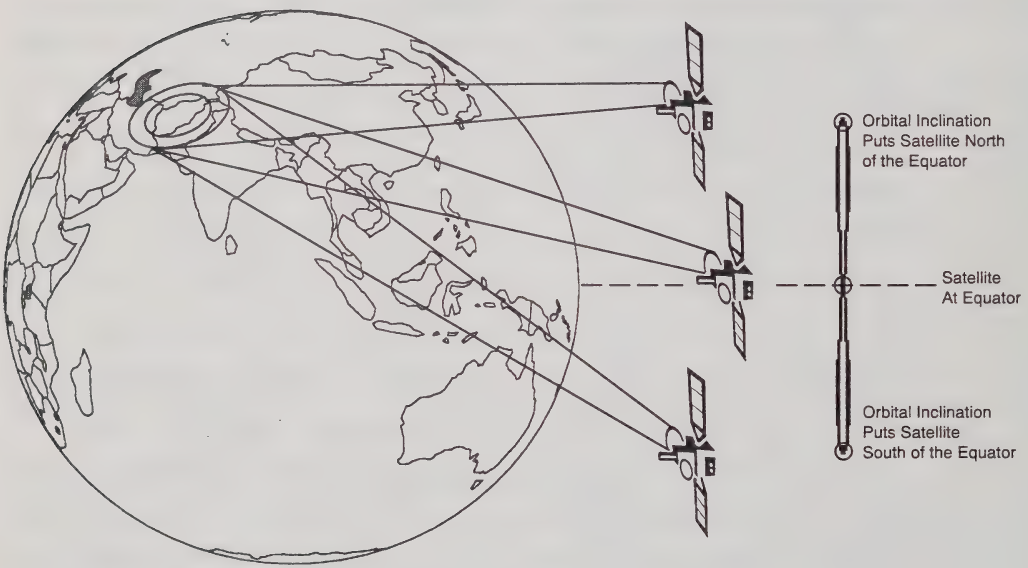
Limitations of the Comsat Maneuver

Because there will remain a certain degree of beam movement over the course of each sidereal day—resulting in some variation in the downlink signal's effective isotropic radiated power or EIRP—it is extremely important that a margin of several dB in receive system carrier-to-noise or "C/N" be factored in to the design on the satellite earth station to compensate for the worst case performance of the satellite at your location. To illustrate the possible effects of beam shifting, a theoretical beam pointing for the Ku-band East spot beam aboard the INTELSAT V F5 satellite located at 66 degrees East Longitude is presented below. With a given inclination of ± 2.5 degrees, saturated beam EIRP would vary between 1.5 and 2.5 dB within the central contours, or even more out towards the beam edge. The illustration provided below expresses the degree of variance through the vertical ellipses over Cairo, Riyadh, and Muscat, assuming a theoretical beam boresight centered on Saudi Arabia. At the time of writing, the Ku-band payload on INTELSAT V F5 was not being used for transmitting telecommunication traffic.

Since orbital inclination would increase at a rate of about ±0.8 degrees per year, the above mentioned variances in EIRP would likewise be expected to increase. The amount of variance would be greater for locations out at the edge of the satellite coverage area, or footprint, than it would be for locations toward beam center. The amount of variance, whether the Comsat Maneuver was being used or not, also would be greatly affected by the type of satellite beam in use.



Inclined Orbit Operations Without Comsat Maneuver



Inclined Orbit Operations With Comsat Maneuver

FIG. 1-11. The effect of the Comsat Maneuver on inclined orbit operations, exaggerated for illustrative purposes.

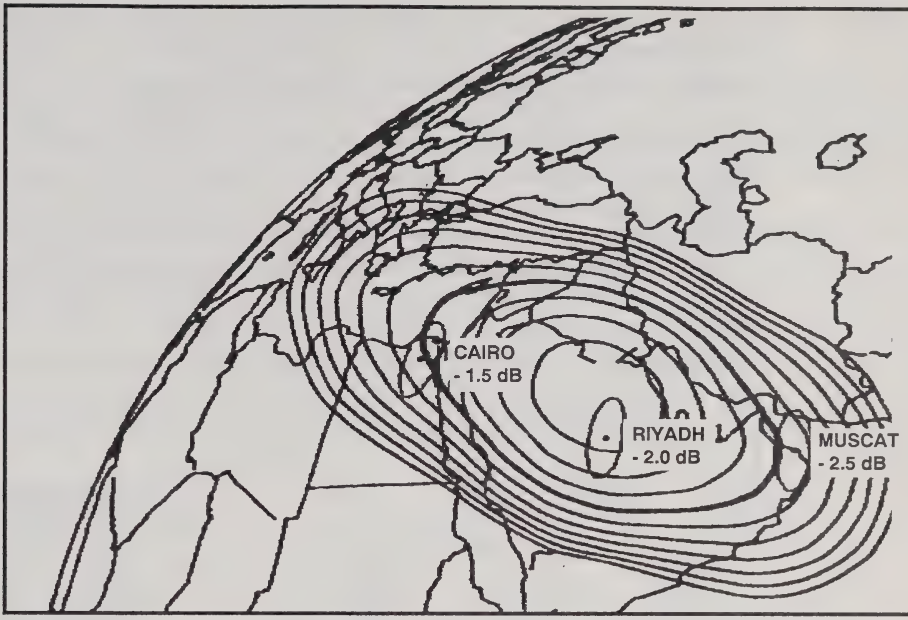


FIG. 1-12. A theoretical example of the amount of EIRP variance which would occur at Cairo, Riyadh, and Muscat for the Ku-band East spot beam aboard INTELSAT V F5 at 66 degrees East Longitude with an orbital inclination of ±2.5 degrees.

Beam Patterns and Inclined Orbit Satellite Reception

All communications satellites carry one or more types of beam antennas: global, hemispheric, zone and spot. For many of the international satellites, the type of beam can be selected by ground command for maximum versatility. The overall effect of inclined orbit operations depends on the type of beam in use.

Global Beams. The global beam pattern covers the largest amount of surface area of the Earth—up to 40 percent. This pattern is used extensively by the INTELSAT and Russian STATSIONAR satellites, particularly when sending television feeds from one hemisphere to the other. These feeds range from short news items of three minutes or less to complete coverage of major sporting or news events.

When a six-watt transponder signal is projected over the global beam area, extremely large dish antennas are necessary to pull in the weak, thinly spread signals. Global coverage signals are still of interest to the experimenter who can get a picture of sorts by using variable bandwidth reception techniques.

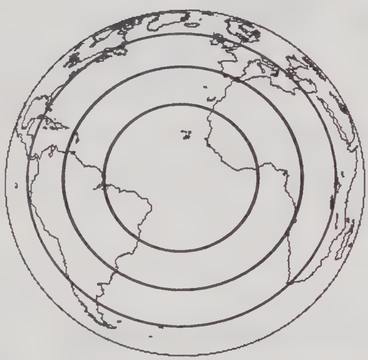
Global beam EIRP is the least affected by inclined orbit operations because the distance between contours is so great, and the change in EIRP from

contour to contour is only 1 dBW. Sites located at the extreme North or South of the coverage pattern would be most affected.

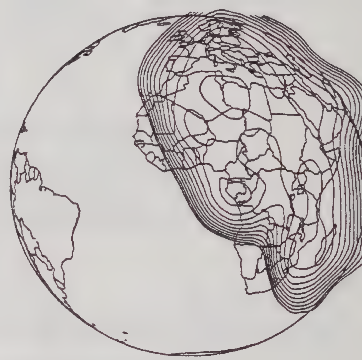
Hemispheric Beams. Several countries lease INTELSAT East or West hemispheric beam transponders, or STATSIONAR Northern hemispheric beam transponders to provide domestic and international television coverage. By narrowing the satellite's beam pattern, the hemispheric beam covers just 20 percent of the earth's surface. This allows smaller and less expensive receiving antennas to be used down on the ground. Reception of hemispheric beam transmissions is possible by earth station antennas in the four to five meter range, with crystal-clear reception usually requiring a dish at least six meters in diameter.

Zone Beams. The zone beam transmits its signal into an area less than

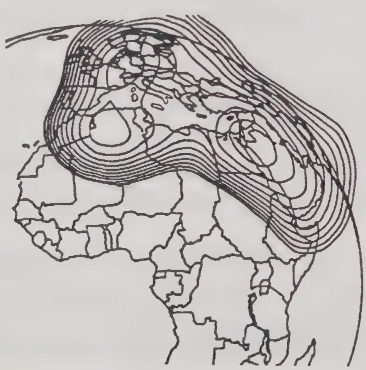
FIG. 1-13. Representative INTELSAT Global, Hemispheric, Zone, and Spot Beam Footprints.



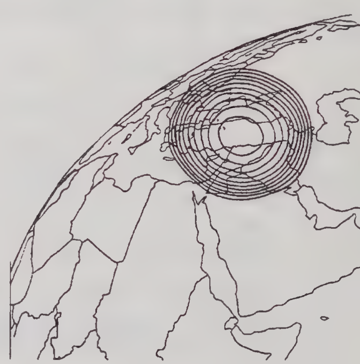
INTELSAT global beam coverage



INTELSAT east hemispheric beam



INTELSAT northeast zone beam



INTELSAT Ku-band spot beam

half the size of a hemispheric beam. This doubles the signal intensity, allowing dishes four meters in diameter to perform effectively.

For locations towards the edge of the beam patterns, Hemispheric and zone beam EIRP will vary more for the INTELSAT than for the STATSIONAR satellites because the contours are more closely spaced for the INTELSAT beams than for the STATSIONAR beams. Again the amount of variance will be the greatest towards the edge of the beam coverage area.

The relatively wide distance between contours of the Russian STATSIONAR satellite beams is due to the fact that these footprint patterns were expressly designed to accommodate inclined orbit operations. While the Russians have long excelled at the technology of launching communications satellites, only recently have their satellite engineers been able to design spacecraft which are light enough to be able to carry the required amount of

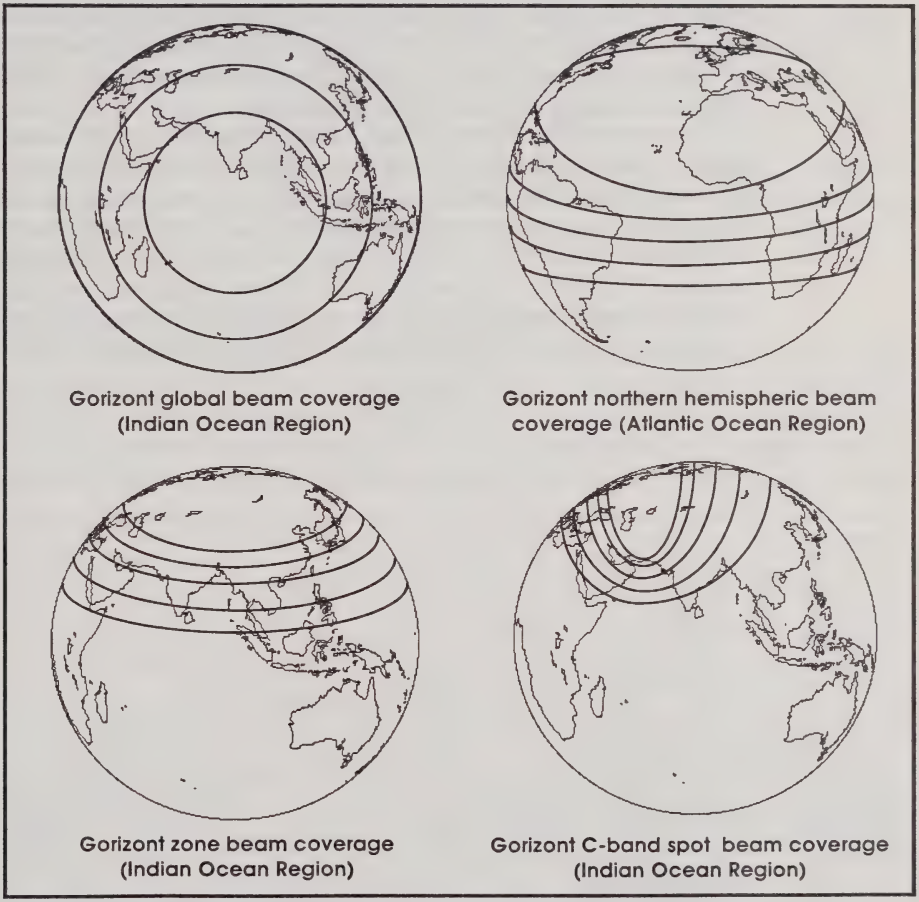


FIG. 1-13. Typical Gorizont global, hemispheric, zone and spot beam coverage beams.

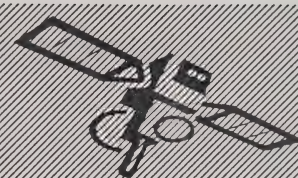
stationkeeping fuel to permit full geostationary operations for more than a two to three year period.

Spot Beams. Many international satellites and all domestic satellites carry more concentrated spot beams. INTELSAT V satellites, for example, carry two steerable Ku-band spot beams that can be commanded to point at any location North of the Earth's equator that is visible from the satellite's orbital position. In addition to their Ku-band spot beams, the INTELSAT V-A satellites also carry steerable C-band spots. The INTELSAT V-A F13 and F15 satellites have been modified to direct their C-band spot beams over locations South of the Earth's equator, including South America. Both the C- and Ku-band spot beams can deliver domestic television and telecommunications services into small-diameter antennas that are located within their respective coverage areas.

Spot beam reception is more affected by the signal variance associated by inclined orbit operations because the distance between contours is so small. In fact, sites located near the edge of the beam pattern may find that their reception will degrade so much during portions of each sidereal day that normal reception is impossible to achieve.

In the case of the C-band STATSIONAR satellites of the Gorizont class, the high powered C-band spot beams have been designed to work with 1.8 meter (6 foot) "Moskva" downlink terminals. These small aperture receiving antenna have a wide enough beamwidth to allow continuous reception of an inclined orbit Gorizont satellite's spot beam throughout its diurnal range of motion. The amount of variance in EIRP is compensated for by increasing satellite transmission power by several dBW more than what would be necessary for comparable reception from a truly geostationary satellite.

CHAPTER TWO: TRACKING INCLINED ORBIT SATELLITES



The amount of difference between the direction in which the antenna is pointing—the beam focus or "boresight" of the antenna's main axis—and the actual direction of the satellite is called the "pointing error". For small amounts of inclination, the motion of an inclined orbit satellite appears as a virtual straight line that is perpendicular to the geostationary satellite arc. This line can be tracked by the motorized receiving earth station with a minimal number of pointing errors.

As the inclination of the satellite grows, however, the width of the figure-eight also expands, causing an increase in the amount of pointing error and a corresponding decrease in the amplification factor or "gain" of the receiving antenna. Any decrease in antenna gain can cause a reduction in the overall performance of the satellite receiving system.

There are several factors which influence the impact of antenna pointing error: antenna size or "aperture", the satellite frequency band in use, the type of parabolic curve used by the antenna designer, and the width of the inclined orbit's figure-eight ellipse.

The Effect of Reflector Size on Antenna Beamwidth

The perfect parabolic antenna would create a narrow receiving beam that would only amplify signals emanating from a radiating source located to the front and center of the dish. In reality, every parabolic antenna has its own unique receiving pattern which illustrates how much receive gain will be given to signals emanating from any given direction. This pattern consists

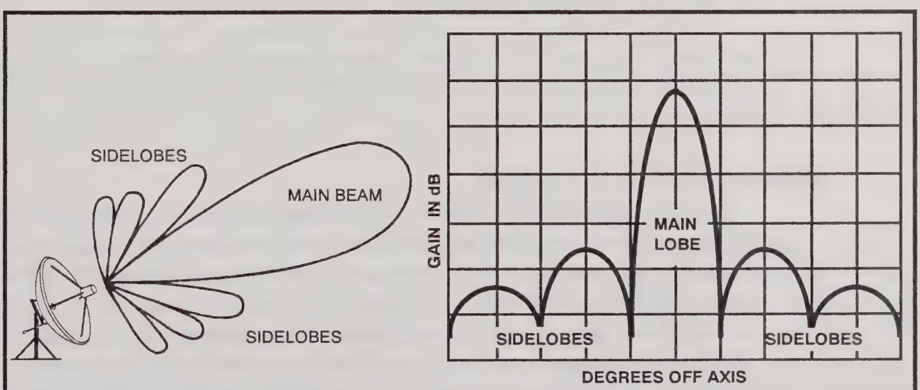


Fig. 2-1. Antenna radiation pattern.

Fig. 2-2. The solid-line circle illustrates antenna boresighted onto the satellite with no pointing errors; the broken-line circles show that pointing errors have occured, but the satellite still falls within the 3 dB contours of the antenna's main beam.

a strong "main beam" located to the front and center of the antenna and lower level side beams or "lobes" which are located to either side.

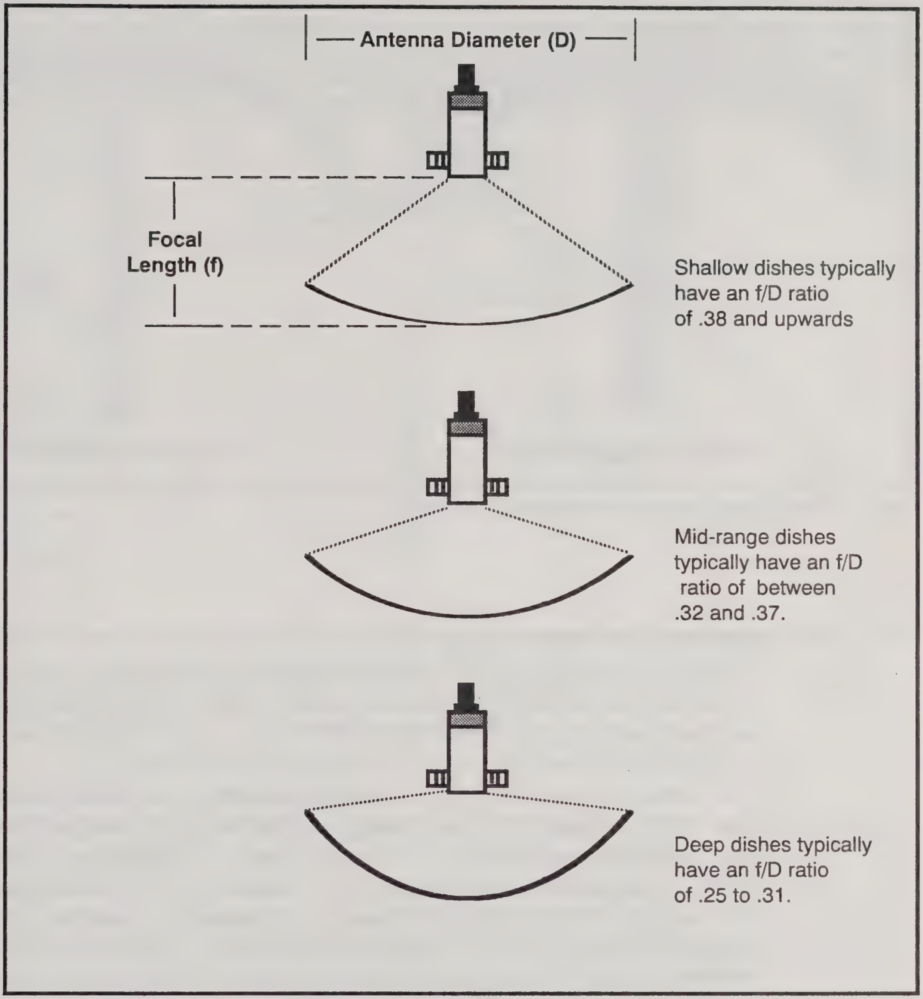
The main beam of a parabolic antenna is defined as having a "beamwidth" of 3 deciBels (dB)—a logarithimic measurement scale first developed by Bell Labs for discerning minimal changes in the levels of communications signals. A 3 dB beamwidth means that the received signal can vary by as much as 3 dB depending on which part of the main beam is directly focussed onto the satellite. If pin-point accuracy is achieved, then the amount of signal loss due to pointing error would be 0 dB. On the other hand, if only of the edge of the main beam is directly pointed at the satellite, then - 3 dB—or half of the incoming signal's power—would be lost!

As the diameter of an antenna increases, the beamwidth becomes more narrowly focussed. A tighter beam means that even small inaccuracies in antenna pointing can result in a significant change in the level of the received signal.

Antenna Reflector Design

Depending on the nature of the parabolic curve selected by the antenna designer, the depth of any dish can vary between extremely "shallow" to very "deep", or various points in between. The beamwidth for any parabolic antenna of a given size or "aperture" is directly affected by whether a deep or shallow dish design is employed. With a deep dish, the focal length—the distance between the feedhorn/LNB assembly and the inner surface of the reflector—is relatively short, while shallow dishes have a longer focal length which positions the feedhorn and LNB a greater distance from the center of

Fig.2-3. Focal length to antenna diameter (f/D) ratios.



the dish. Deeper dishes will have a narrower beamwidth than shallower antennas for a given antenna aperture.

The Effect of Frequency on Antenna Beamwidth

As the frequency of the received signal increases, the focus or 3 dB beamwidth of the antenna decreases, which is why an antenna will focus more narrowly when receiving Ku-band signals—and therefore experience a greater reduction in gain for a given amount of pointing error—than when receiving C-band signals. To reduce the amount of pointing error, a Ku-band receiving antenna will have to track the inclined orbit satellite more precisely than a C-band antenna of equivalent size.

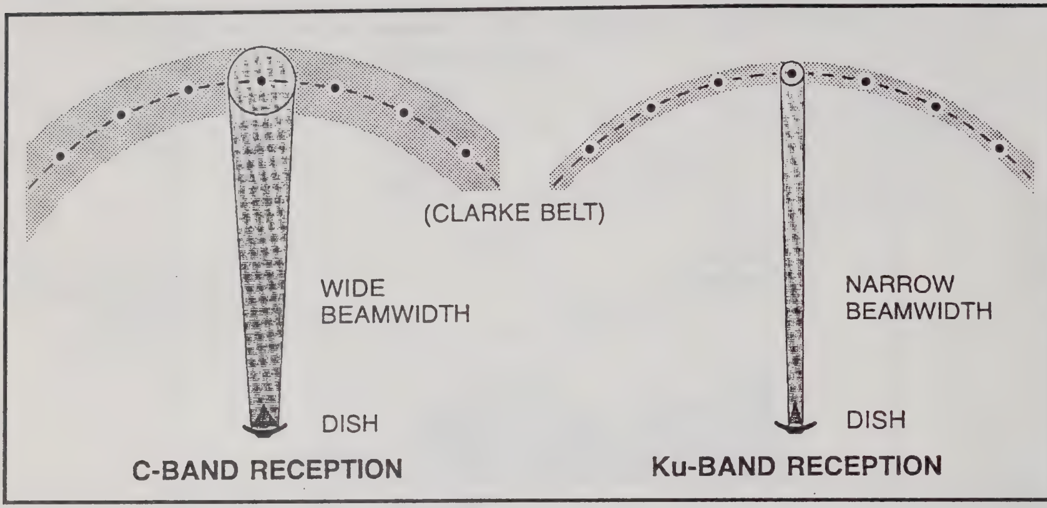


Fig. 2-4. The effect of frequency on antenna beamwidth.

The Width of the Figure-Eight Orbit

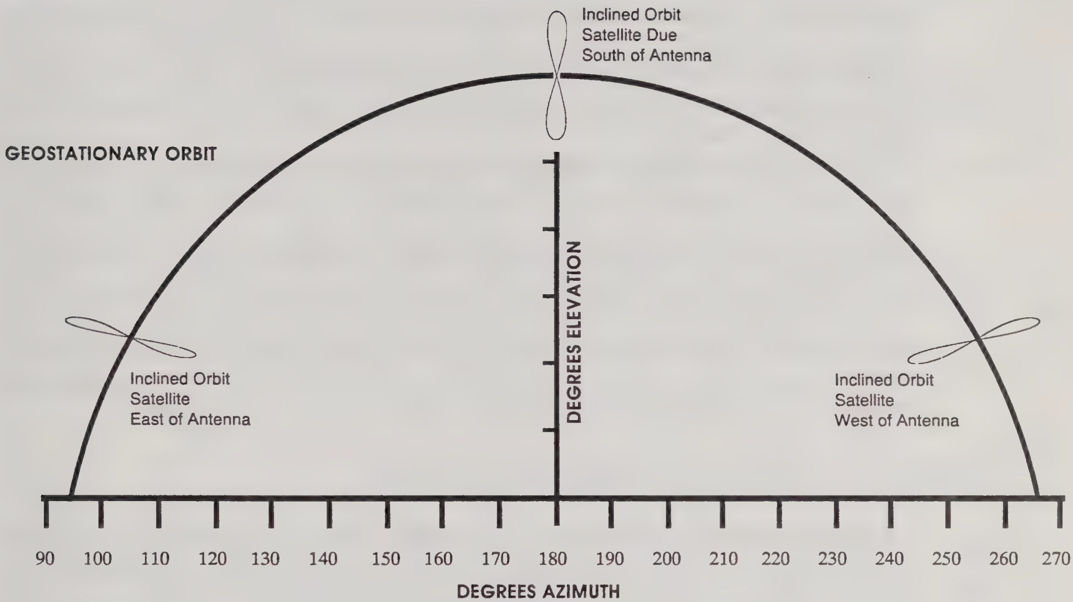
The diurnal motion of an inclined orbit satellite traces an elliptical "figure 8" pattern in the sky. The precise dimensions and orientation of the ellipse depends on the geographical location of the receiving earth station relative to the satellite and the degree of orbital inclination.

To precisely track the motion of the inclined orbit satellite through its 24-hour sidereal day, antenna pointing must be periodically adjusted to follow the satellite's movement. "Azimuth" and "elevation" are the two basic coordinates used to determine an inclined orbit satellite's precise position in the sky at any point in time. The azimuth coordinate represents the compass bearing of the satellite (corrected to true North) from the site location, while the elevation is the angle at which the dish looks up at the satellite.

For satellites located nearly due North or South of the receiving site, the apparent satellite motion is a thin vertical figure-8 pattern and the required tracking motion of the antenna is nearly all in elevation. For antenna locations which lie East or West of the satellite's longitudinal position over the Earth, the figure-8 pattern tilts from vertical while remaining essentially perpendicular to the satellite arc.

As the difference in longitude between the receiving site and the satellite increases, the required tracking motion for maximum reception acquires greater amounts of azimuth. When the two longitudes differ by a large value, i.e. the satellite is located relatively near to the site's Eastern or Western horizons, the main tracking motion will be in azimuth.

Fig. 2-5. For satellites nearly due South (or due North for locations South of the Earth's equator) of the receive site, the apparent satellite motion is a thin vertical figure-8 pattern and the required tracking motion of the antenna is nearly all in elevation. If the antenna is East or West of the satellite the figure-8 pattern is tilted from vertical while remaining essentially perpendicular to the satellite arc. As the satellite and receive site differ more in Longitude, the required motion is in both azimuth and elevation. When the two Longitudes differ greatly, the tracking motion is nearly all in azimuth.



Minimizing Antenna Pointing Error

Satellite system manufacturers try to maximize the incoming signal strength while keeping external and internal noise to a minimum. This relationship is expressed as the Carrier To Noise Ratio (C/NR). Every receiver has a threshold point (expressed in dBs C/NR). When the C/NR falls below this point, the video rapidly becomes noisy. Once the C/NR is a dB or more above threshold, impulse noise or sparklies" dissapear.

It therefore is extremely important to keep the satellite system operating above the receiver's C/NR threshold. The amount in dB that the system must exceed this threshold in a TVRO system is governed by whether the earth station is dedicated to providing home satellite TV, Cable TV, or broadcast TV services.

One way to counteract the adverse effect of antenna pointing error is to factor a signal safety margin of 3 dB in carrier-to-noise ratio (C/NR) into the design of the receiving system. Therefore the earth station will receive sufficient signal for adequate operation as long as some portion of the main beam remains pointed at the satellite at all times. This 3 dB margin is commonly achieved by selecting a receiving antenna with a larger aperture. For example, a 4-foot C-band antenna can produce a gain of 32.5 dB (70%

efficiency), while a 6.5-foot C-band antenna can produce a gain of 35.5 dB (70% efficiency). Keep in mind, however, that the antenna tracking mechanism must be accurate to maintain pointing within the antennas 3 dB beamwidth for this to be an effective strategy.

During the first few months following the inception of inclined orbit operations for a given communications satellite, the amount of movement will be insufficient to take the location of the satellite outside of a small aperture antenna's 3 dB beamwidth. If sufficent margin has been calculated into the design of the earth station, then there will be no adverse effect on system performance.

However, eventually the satellite's movement will increase to a level that does take the satellite outside the receiving antenna's main beam for significant portions of each day. At this point, the receiving antenna must be equipped with a tracking mechanism if the satellite is to be continuously received. Two different types of motorized tracking systems commonly are available: single axis and dual axis. The type of tracking system used will depend on the kind of mount which the receiving antenna has and the level of tracking accuracy which the antenna must achieve in order to maintain the required level of performance.

Antenna Mounts and Inclined Orbit Tracking

Azimuth over Elevation (Az/El) Mounts. Most small aperture voice and data communications antennas and larger commercial grade antennas are equipped with Az/El mounts. Antennas on Az/El mounts can be moved in either the azimuth (East/West) or elevation (up/down from the site horizon) directions. If the antenna is situated within approximately ± 5 degs. of the

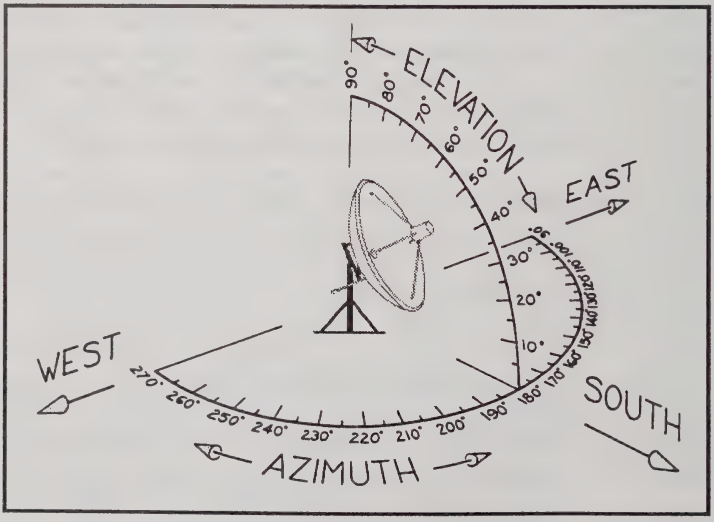


Fig. 2-6. Azimuth and Elevation adjustments for satellite antenna located in the Earth's Northern hemisphere.

satellite's longitudinal assignment over the Earth's equator, the inclined orbit satellite will appear to be moving in elevation only. In this case only the elevation axis needs to be motorized for tracking through the center of the figure eight motion of the satellite and a less expensive single axis controller will be all that is required. At all other locations both axes will have to be motorized for Az/El mounted antennas to track inclined orbit satellites accurately.

Several manufacturers with dual-axis antenna controllers are listed later in this book. It should also be noted that manufacturers of extremely large commercial antennas (7 meters on up) provide Az/El mounts with both axes motorized so that even geostationary satellites can be precisely tracked as they move within their assigned +/- 0.1 degree "orbital box".

The "Modified" Polar Mount. An offshoot of the True Polar Mounts long used by astronomers for pointing their telescopes at celestial targets in the sky, "modified" polar mounts are used by earth stations which commonly receive more than one communications satellite. These mounts track the satellites along the geostationary arc by means of a single East/West adjustment in direction called the "actuation".

Because of the relative closeness of satellites as opposed to the stars and planets, the modified polar mount must have an axis which is inclined a fraction of a degree toward the Equator from parallel to the polar axis of the Earth. It is this parallelism which calls for the quotation marks surrounding the word "modified" preceding the word polar. To observe satellites in geosynchronous orbit, satellite antennas are further tipped from their mount's modified axes toward the equator by a small angle which is called the "declination".

The modified polar mount used for receiving geostationary satellites has a single motorized actuator which moves the antenna in the East/West direction. This type of mount can be retrofitted for inclined orbit tracking by replacing the mount's fixed elevation adjustment rod (or turnbuckle) with a second motorized actuator arm so that the antenna can be adjusted in both the East/West and Up/Down directions. However, unless the antenna is located at virtually the same longitude as the satellite to be tracked, movement of the antenna is required in both East/West and Up/Dopwn directions for optimum reception.

A more accurate modification to the modified polar mount is to motorize the antenna's declination axis. A single movement in declination will point the antenna virtually up the middle of the figure eight ellipse. As we have noted earlier, the figure eight movement of the satellite is perpendicular to the geostationary arc. Once the antenna has been moved to the East or West along its polar axis to the correct "hour angle" setting for the satellite, movement in the antenna's declination axis also will be at right angles to the geostationary arc.

Unfortunately, many of the lower-cost home satellite TV antennas being

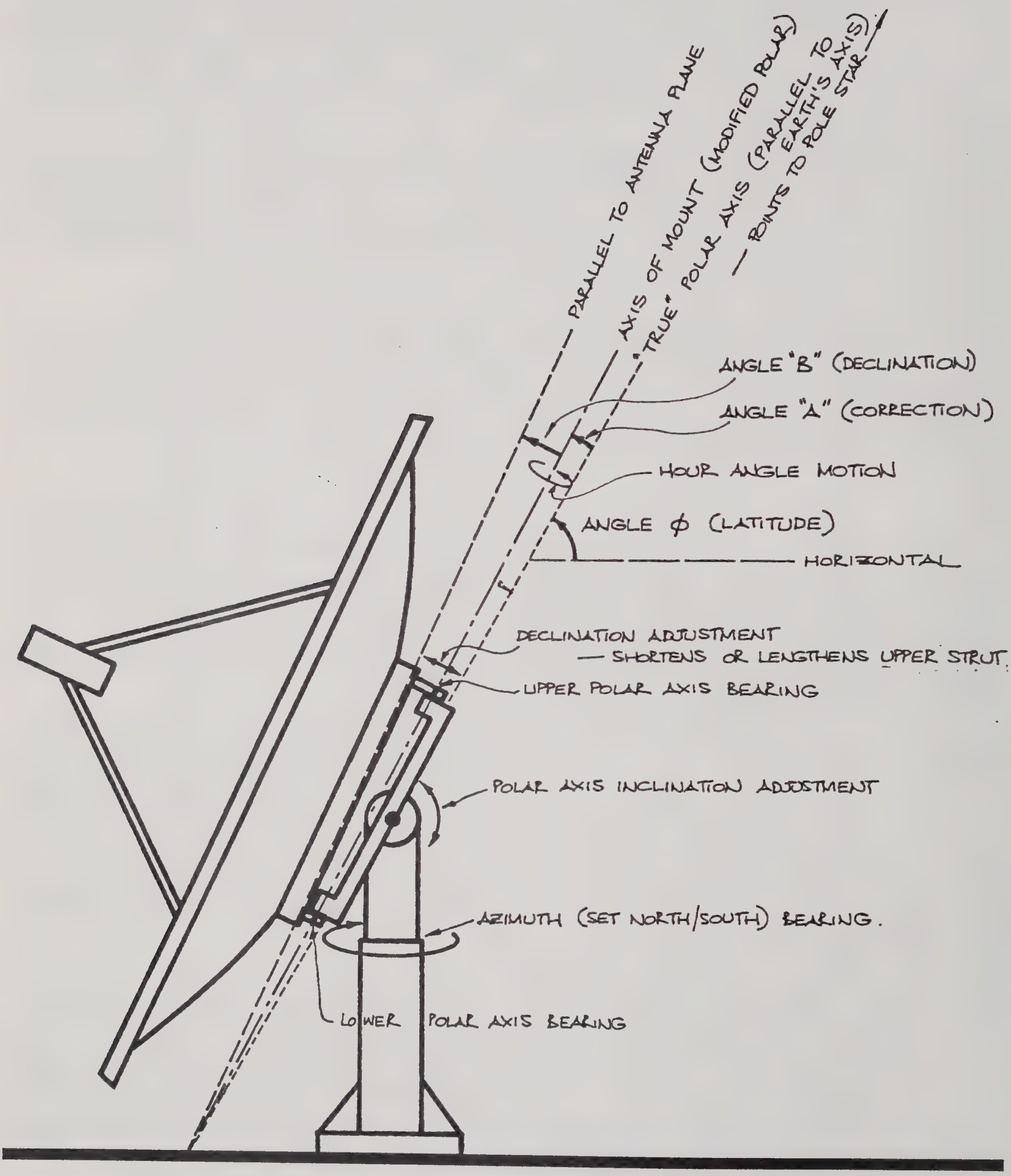


Fig. 2-7. Modified Polar Mount Antenna Adjustments. (Courtesy Stephen J. Birkill.)

manufactured today have a fixed declination adjustment inserted between the parabolic reflector and the modified polar mount. All too often, this fixed declination adjustment is not easily motorized. Therefore, a new bearing axis may need to be installed in place of the fixed declination adjustment before a motor can be added.

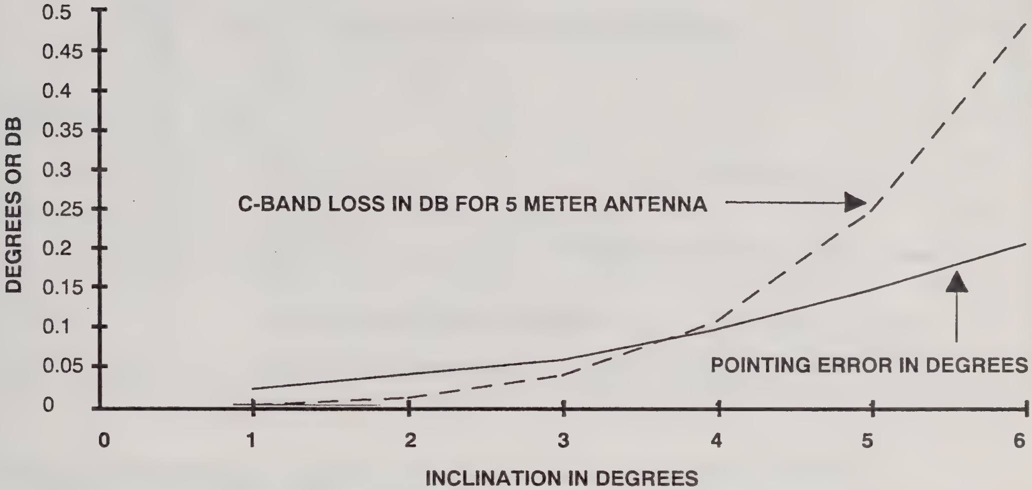


Fig. 2-8. The loss in decibels for a five meter C-band antenna - less than one half dB even for a large degree of inclination. (Courtesy of Merrimac Satellite.)

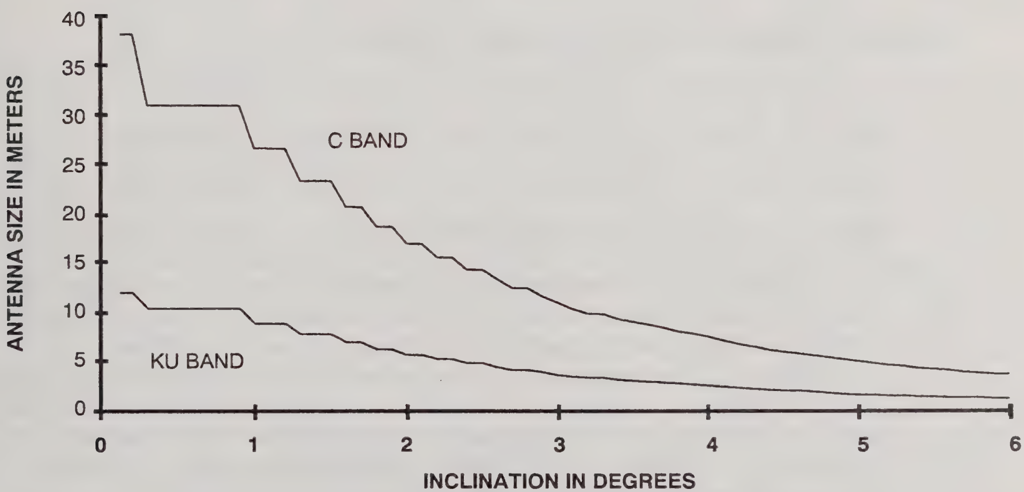


Fig. 2-9. The maximum antenna size allowable for less than 1.5 dB loss due to pointing errors at both C and Ku band. It can be seen that, except for very large antennas or very large orbit inclinations, the worst case losses due to single axis tracking will be minimal. (Courtesy of Merrimac Satellite.)

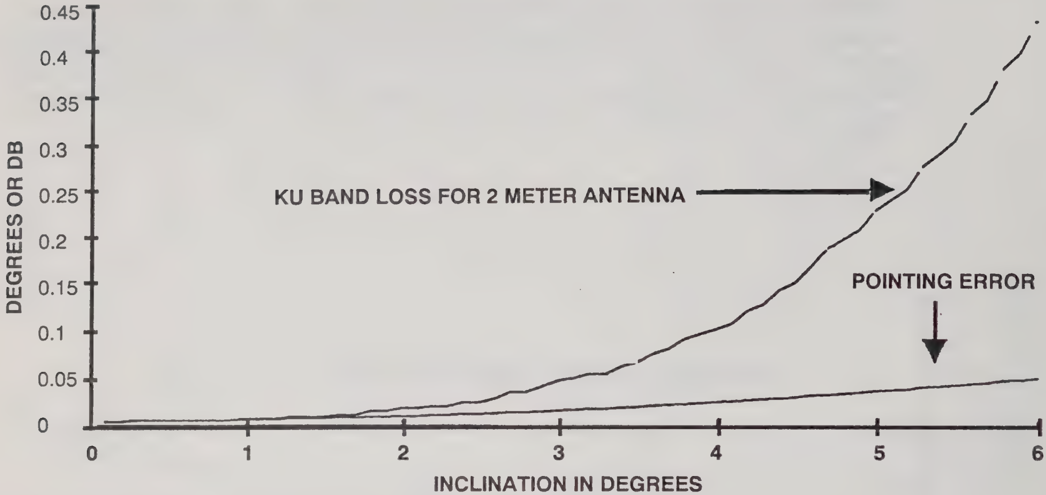


Fig. 2-10. The effect of inclination on single axis tracking—worst case values. (Courtesy Merrimac Satellite.)

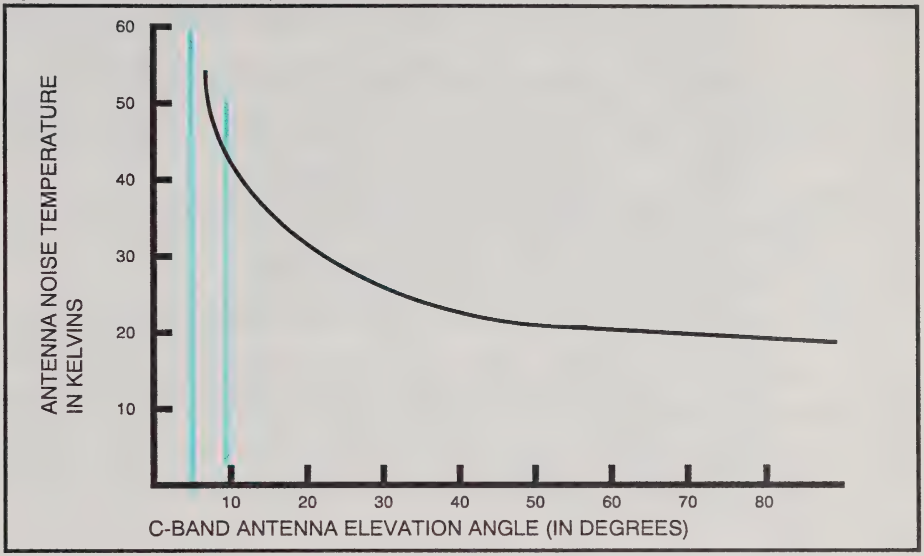
It is less costly, and therefore most desirable, to be able to track the satellite using movement on only a single motorized axis. By causing the antenna to track through the center of the figure eight, pointing errors due to the width of the figure eight will occur.

Tracking Satellites At Low Elevation Angles

Whenever an inclined orbit satellite appears at a location in the sky which is relatively near a given site's Eastern or Western horizons, the receiving antenna must be tilted almost on edge in order to receive the incoming signal. Satellite receiving antennas which operate at low elevation angles are more susceptible to performance degradations caused by the high noise temperature of the Earth itself. Since the antenna is tilted toward the Earth, the high noise temperature is "seen" by the antenna along with the incoming satellite signal. The following chart illustrates that at low look angles, minor changes in elevation can cause a substantial rise in the noise temperature of the receiving system, thereby degrading system performance.

INTELSAT, for example, sets the effective antenna elevation limits for its earth stations at 5 degrees (C-Band) and 10 degrees (Ku-Band) above the local horizon for any given geostationary satellite. Keep in mind that an inclined orbit satellite that requires a 5 degree (C-band) or 10 degree (Ku-band) antenna elevation angle when it crosses the equator may actually dip substantially below the 5 or 10 degree limit for major portions of each 24-hour sidereal day. In extreme cases the inclined-orbit satellite may even drop so close to the horizon that there is a complete loss of service.

Fig.2-11. Antenna noise temperature chart.



Other Limiting Factors

There also are several incidental limiting factors which have a minimum impact on TVRO installation, but a rather more substantial impact on the transmission of voice and data signals via satellite. These include polarization isolation, the doppler effect, and the pointing accuracy of commercial VSATs and extremely large international gateway earth stations.

Polarization Isolation. Almost all communications satellites maximize their use of the limited frequency spectrums assigned for satellite communications by overlapping the channels or "transponders", with signal polarization switching from one sense of polarization to the opposite sense every other transponder. Most domestic communications satellites use linear polarization, where the transmitting satellite radiates the signal in either a relatively vertical (straight up and down) or horizontal (lying flat) polarization as seen from the satellite. Many international satellites—including those operated by Intelsat and Intersputnik—as well as all high-powered DBS satellites, use an alternate polarization format known as circular polarization. Instead of beaming the microwave energy along a "linear" plane, whether vertical or horizontal, circular polarization is transmitted in a helically rotating pattern, rotating either in a clockwise (left-hand circular) or counterclockwise (right-hand circular) direction as seen from the satellite.

As the pointing error increases, the isolation between transponders of opposite polarization decreases, thus causing the antenna to both transmit and receive more interference from oppositely polarized transponders on the same satellite.

The movement of a satellite along its inclined orbit can induce minor changes in the orientation of signal polarization as seen from locations down on the ground. For TVRO applications, however, it has been found that these moderate changes in polarization actually have little effect on the received signal. In cases where the picture may become degraded, a simple adjustment, either manual or automatic, of the receiving system's polarization setting or "skew" can re-peak the signal.

The Doppler Effect. Similarily, doppler frequency shift—the effects of a delayed signal when transmitting to and receiving from a moving satellite—only has a slight effect in TVRO situations.

Large Aperture Earth Station Pointing Accuracy. Pointing accuracy for large commercial antennas at teleports or even for smaller VSAT (very small aperture terminal) voice and data networks is much more critical than for home TVRO systems. Intelsat and other commercial satellite operators must operate under much tighter tolerances than those designed for other applications. For this reason a wide range of satellite tracking systems are on the market. These systems vary greatly in size, method of operation, and price.

Antenna Control Units (ACU's)

Antenna motor controllers which can move the antenna either along one or two mount axes but do not automatically track the movements of the satellite are refered to as "manual" positioners, while "automated" positioners use computer microprocessors to keep track of the precise location of the satellite in the sky at any given time.

The Monopulse Tracking System. "Monopulse" position controllers use the satellite signal to keep track of the satellite's position. Positioning information is obtained by "differencing the output of feedhorns which are offset from the focus of the antenna, or by sensing asymmetric waveguide modes in a single feed horn. If the antenna is pointing directly at the satellite the difference signal should be zero." When it senses a difference in signal strength from one to the other it signals the dish to move to re-establish a balance. Although monopulse controllers can be highly accurate and be used to track fast moving satellites, they can be very expensive because they require up to four feedhorns, LNBs, and receivers. The monopulse system also has a tendency to move the antenna continuously during certain atmospheric conditions which cause signal fluctuations. This unnecessarily increases the wear on the drive mechanism.

The Steptracking System. A steptrack system periodically moves the antenna in small increments in each direction while correlating the received signal level with the antenna's position. After searching within this box and locating the position where the signal is the strongest, the antenna is moved to the position of strongest reception where it remains until the next search begins. Searches are either initiated after a certain amount of time has

elapsed or set to begin when the signal level falls below a predetermined level. This signal level reading is usually supplied by the AGC circuit of the receiver.

Auto peaking with the steptrack system is one of the least expensive and simplest operating tracking modes. For many applications, antennas which offer motorized declination adjustment can do a sufficient job of tracking the satellite with this single motorized movement.

The Predictive Tracking System. Because the steptrack system does not have the ability to memorize the positions of the satellites or to predetermine their position, the antenna must go through its searching motions quite frequently. With the self programming "predictive" mode of tracking, however, a microprocessor is added which greatly reduces the amount of searching involved.

Similar to steptracking, the antenna controller peaks the antenna based on received signal strength and then records the position at which maximum signal strenth has been achieved. After a definable time period—or when the signal strength falls below a predetermined threshold—a new peak is performed and a new position is recorded. Eventually, the antenna controller has programmed into its memory a "map" of the satellite's orbital movements. By following this map, the controller can anticipate the required movement and automatically initiate the required changes in antenna positioning.

The program is set so that after a certain period of time the tracker will search for a signal peak to verify that it is still tracking accurately. If not, it will start the process of memorizing a new map of the satellite's orbital movements. This is particularly helpful in the case of Intelsat and Russian satellites, when an older satellite with a high degree of orbital inclination is replaced by a newer with a lower level of orbital inclination.

Program Track Systems. Software programs also can be written to steer the antenna in accordance with the predicted movement of the satellite over time. Since these preset "program track" systems do not rely on feedback from the satellite receiver or feedhorn, the controller will only move the antenna when instructed to by the software program. This saves excessive wear on the positioning mechanism which must be aligned percisely to maintain tracking accuracies. The computer has no provision for confirming it is following the satellite path and the software may have to be updated periodically with new tracking data.

Hardware Selection

There are several different ways that a receiving earth station can be modified to allow continuous reception of inclined orbit satellites. There also are available a wide range of antenna control units (ACUs) and operating software designed for inclined orbit satellite tracking. These different systems will vary greatly in size, price, and tracking accuracy. The application for which the earth station is being utilized will have the greatest bearing on the amount of tracking accuracy

required and is therefore the main criteria for selecting the appropriate equipment. We have included here—in alphabetical order—a partial list of manufacturers offering mounts, ACUs, software and hardware solutions for inclined orbit satellite tracking.

Tracking Hardware Manufacturers - Antenna Control Units (ACU's)

Andrew
10500 West 153rd Street
Orland Park, Illinois 60462
Phone (708) 349-5530
Fax (708) 349-5444
Watts (800) 255-1479

Andrew is a commercial antenna manufacturer which also produces a steptrack antenna controller (APC300) featuring multiple control functions. The pure steptracking mode of operation uses a special beacon receiver or the AGC from a video receiver to sample the satellite's signal level. The antenna is moved to various points around the nominal satellite position until the position producing the greatest signal strength is found. This process is continually repeated to keep the satellite signal strength at its peak.

The Andrew Smartrack™ method builds a data base of predicted satellite positions for a 24-hour period. From the data base, perdictions are reviewed once every minute. The antenna is automatically repositioned whenever the predicted position differs from the current pointing position by a user-defined amount. The data base includes signal strength information which is used in conjuction with user-defined parameters to decide whether or not the current signal is correct.

Upon reaching the predicted satellite position, Smartrack evaluates the satellite signal strength, previously-recorded satellite data and recent steptrack activity. If the signal strength is within user-specified parameters, no futher action is performed. If the signal is not within the prescribed boundary, the unit begins a new steptrack cycle. The new position coordinates are used to update the Smartrack database to predict the satellite's future position.

If the positioning cycle fails to improve the signal strength, Smartrack will not initiate a new steptrack cycle for a user-specified period of time. It continues to follow its own predicted path. This design feature allows the satellite to be tracked normally during rain fades or beacon outages.

For program-track operation, satellite position data is loaded in the data base from a computer program. These predicted satellite positions are then down-loaded to the steptrack controller. Finally Smartract takes over and keeps the antenna pointed to the correct position.

Astroguide
1403 Fifth Street
La Salle, IL 61301
Alan Howarter, Marketing Director
Phone (815) 224-2700
Fax (815) 224-2701

The Astroguide Trax IIE dual axis controller can track up to four inclined orbit satellites and store the positions for 32 geostationary satellites. The unit starts out in the step track mode. During the first 24 hours of operation the Trax IIE builds a map of 231 points where the strongest signal was found, supplied by either an external receiver or optional internal receiver board. It then automatically follows this map on subsequent days. The Trax IIE will update the map on command from the front panel, at preset intervals, or continuously.

The Trax IIE can stand alone or be controlled by a remote computer. The software also can be configured to operate single axis tracking. Moreover, Astroguide also offers heavy duty Az/El mounts for antennas up to 10 meters in diameter and ACU interfaces which can drive AC motors. (See photo 2-1 which appears on page 48.)

Echosphere Corporation
90 Inverness Circle East
Englewood, CO 80112
Phone (303) 799-8222
Fax (303) 799-8878

The EchoStar Nomad II dual axis auto tracking system is private labeled for Echosphere by Research Concepts, Inc. For further information, see the RC2000A listed below under Research Concepts, Inc.

Farranti International plc
Satellite Communications & Microwave Components
First Avenue
Poynton
Stockport
Cheshire
SK12 1NE
United Kingdom
Phone 44 625 871611
Fax 44 625 859843

Farranti International's ACU 1000 can be configured to operate either in manual, step track, or program track modes. From the step track mode, it also is capable of accumulating satellite position data to build up an internal model of expected satellite motion. It then uses this information to gradually improve

the tracking accuracy by predicting to where the satellite will next move. This feature is called "Smooth Track".

The ACU 1000 is available as a basic manual positioner. Upgrade kits can then be added to provide the necessary plug-in cards and software to include program track, "smooth track", or even remote operation of commands and controls. Since the ACU 1000 obtains its tracking information from the satellite's beacon signal, a beacon receiver also will be required, such as Farranti's SBR 100.

Merrimac Satellite
327 Palisade Street
Merrimac, WI 53561
Bart Olson, President
Phone (608) 493-2291
Fax (608) 493-2074

The MS-1 hardware consists of a dedicated microprocessor system along with power supplies to operate two 36 volt DC motors. An RS-232 interface allows communications with most PC-based computer terminals.

The MS-1 uses signal strength from the receiver to locate and track up to two inclined orbit satellites. The initial setup includes establishing a window of operation for each satellite and setting the time and date. Once each satellite has been tracked for a day, it may be found using the logged data. As the MS-1 tracks each satellite, the system continously updates the position data in the log.

The MS1 also functions as a geostationary satellite finder and time based controller. Locations of up to 42 satellites can be entered into a list so that they can be quickly located by entering the satellite name. Up to 20 entries can be made on the time log for moving the antenna to a satellite on any date, day of the week, or every date at a given time. Each of these satellites may also be flagged as needing tracking, so that they may be continously tracked but without the position data being logged.

Merrimac also offers the less expensive MS-3 single axis tracker. Using a signal strength voltage from the satellite receiver, the MS3 drives a potentiometer-equipped actuator on the elevation or declination axis of the mount to track the inclined orbit satellite using a steptrack algorithm. The MS-3 also allows manual movement of the dish and automatic movement of the dish back to a preset point. Also available: universal dual axis mounts which can accommodate several different brands of antennas.

Research Concepts, Inc.
Contact: Paul Gabel
10679 Widmer
Lenexa, Kansas 66215
Phone (913) 469-4125
Fax (913) 469-4168

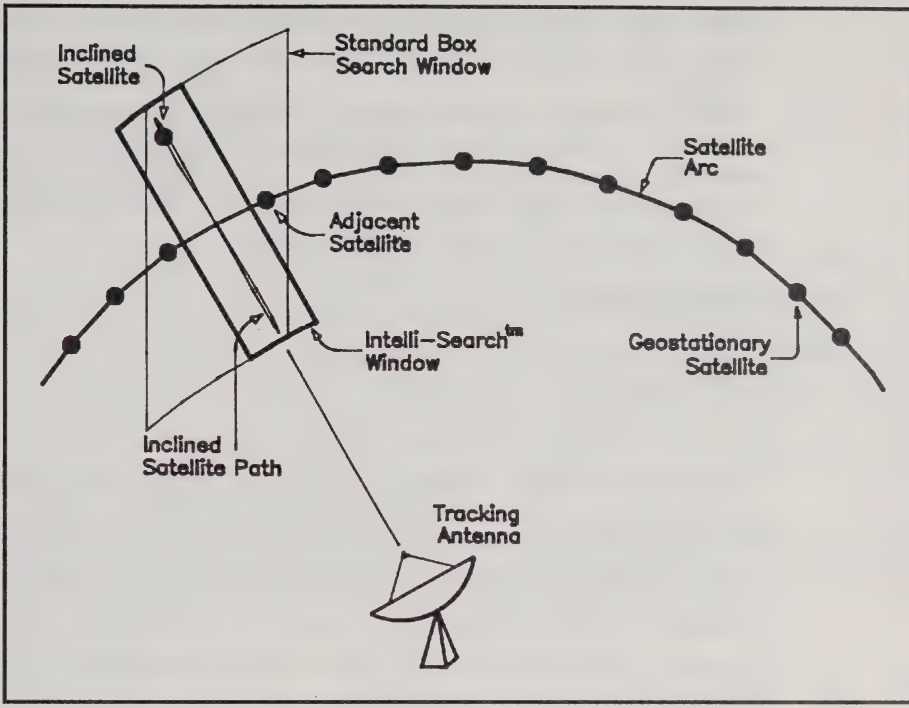


Fig. 2-12. The RC2000B Intelli-Search Advantage. (Courtesy RCI.)

RCI's RC2000B dual axis antenna controller—which has a heavy-duty solid-state dual speed drive network rated at 8 Amps output that is compatible with reed, Hall effect, of optical sensors—can track up to 5 inclined satellites plus 45 geostationary ones. Satellite location data is originally collected in what RCI calls the "Intelli-Search" mode (Fig. 2-12). This search algorithm minimizes errors associated with traditional box searches which may overlap adjacent satellites. (See photos 2-8 and 2-9 on page 50.)

The satellite receiver's AGC output or an optional built-in tuner supplies the required signal strength information. After following the movements of the satellite over a 24 hour period, the controller has gathered enough information to construct a "map" of the satellite's diurnal movements and no longer relies on the AGC signal. The controller also will perform a step track check periodically to see if a current reading matches up to the map stored in the controller's internal memory. If not, a new map will be plotted.

Advanced programming features allow the controller to determine if it needs to search for the satellite, proceed in a step track mode, or work from prior data to predict the satellite path in program track mode. The user is also free to determine how closely the RC2000B tracks by specifying an allowable signal loss factor in dB which can be utilized to save wear and tear on the drive mechanism.

The RC2000B POLAR antenna controller is designed to work with modified

polar mount antennas which have motorized elevation or declination adjustments. The RC2000B Az/El antenna controller is designed to work with Az/El mounts.

The RC2000A is a general purpose dual axis antenna controller without the capability to track inclined orbit satellites. The Smart Booster II can boost the amount of power going to two independent motors on the antenna mount and can replace the Drake IOA 600 when interfacing two large antennas requiring more current than the Drake receiver can supply.

R.L. Drake Company
P.O. Box 3006
Miamisburg, Ohio 45343
Phone (513) 866-2421
Fax (513) 866-0806

The Drake ESR 700e international satellite receiver can be interfaced with an optional Inclined Orbit Adapter (IOA 600) to control two actuator drive motors on a single antenna mount. When auto peaking by step tracking, the receiver learns the direction of travel of the satellite's inclined orbit so that when the automatic peaking time arrives, the antenna will be moved in the correct direction. The tracking time is the period of time between executions of the automatic peaking routine. This time can be set anywhere from 10 minutes to 60 minutes in 10 minute increments.

Satellites with a high degree of inclination will require more frequent peaking than those with a lower degree of inclination. Drake assumes that 10 minutes should be sufficient for the tracking time of highly inclined satellites, while a longer period of time between antenna peakings could be acceptable for satellites in slightly inclined orbits. (See photo 2-10 on page 52.)

Satellite Systems Corporation
101 Malibu Drive
Virginia Beach, Virginia 23452
Fred Poteet, President
Phone (804) 463-3553
Fax (804) 463-3891

The model AAP 1011 Satellite-Tracker℠ is a microprocessor-based dual axis ACU which claims accuracy to within ±0.1 degree. Conventional steptracking is used for twenty-four hours to establish baseline satellite trajectory data from the antenna's position sensors. This data is stored in the Array Tracking memory. Stored Array Tracking data then predicts the future trajectory of the satellite. The Satellite-Tracker monitors the received signal while moving the antenna along the path predicted by the Stored Array Tracking memory. Tracking data is constantly refreshed by the steptrack positioning to correct for changes in trajectory over time. Optional features include: a three-

phase motor interface, RS-232 interface, and remote diagnostic capabilities.

Scientific-Atlanta, Inc.
4356 Communications Drive
Norcross, Georgia 30093
Phone (404) 903-6262
Fax (404) 903-6245

The SA Model 8860/8861 Antenna Control System provides manual or automatic antenna positioning of all Scientific-Atlanta earth station antennas. Optional "AdapTrack" predictive tracking software "learns" the inclined orbit satellite's movements either through manual entry or by moving the antenna and plotting peak signal levels supplied by a beacon or a video receiver. As the amount of antenna movement data increases, the software begins to predict when and where the next movement will take place. By comparing these predictions with actual peak positions it becomes more accurate and relies almost entirely on tracking predictions.

The Model 8860 ACU occasionally monitors the signal strength level and compares it to past positions. If there is a significant difference the AdapTrack relearns the pattern of movement. (See photo 2-11 on page 53.)

Sea Tel, Inc.
1035 Shary Court
Concord, California 94518
Patrick Matthews, Pres.
Phone (510) 798-7979
Fax (510) 798-7986
Telex 269909

The Sea Tel SAT90 and HDT91 control units can be used to position single or dual axis antenna mounts or to drive Sea Tel's own Az/El mount. The Sea Tel Az/El mount has been designed for critical VSAT earth station applications and will maintain pointing accuracies of ±0.1 degrees with dish sizes up to 3 meters—even at high winds. Sea Tel's satellite tracking systems also are used onboard ships, floating oil platforms, and to track LEO satellites.

The SAT90 is used to track a single satellite while the HDT91 is able to store and recall up to 24 different satellites, any of which can be in an inclined orbit. The received signal strength is monitored by an external AGC input or by an internal receiver capable of tuning over the standard 950 to 1750 MHz intermediate frequency (IF) band. Optional receiver boards are available for narrowband or beacon tracking applications.

For installation and maintenance operations, the unit is controlled by a computer terminal connected to a RS-232 port on the rear panel. The terminal—a small hand-held is available from Sea Tel—can then be disconnected and does not have to remain dedicated to the system, although the terminal will be

required when recalling a different satellite with the HDT 91.

The ACU aquires its tracking data by first performing a full range search over the expected satellite track to locate the strongest signal level. The parameters for this search are permanently stored in the ACU's non-volatile EPROM memory so they will not be lost during a power outage.

Having located the satellite, the ACU next performs a 24 hour step track cycle. The antenna is kept peaked at the point of maximum signal strength by making small trial movements of the antenna and measuring any signal level changes which take place. At approximately 38 minute intervals, the correct azimuth and elevation positions are stored in memory.

After the ACU has tracked for a full 24 hour cycle, it will have stored a complete map of the antenna positions in memory. For any point between the stored position points, the ACU will compute a new antenna position based upon a linear interpolation between the stored data points. The ACU moves the antenna only as required to follow the path in memory, thus reducing actuator motion and increasing reliability. The number of data points was chosen so that the computational error from this process would be less than ±0.05 degrees.

To allow the data to be updated and to provide greater accuracy for the stored data, a new step track peaking operation is performed at the end of each 38 minute segment interval. The new "peaked" antenna position is then used to update the position stored in memory using a weighted average calculation. The averaging has the effect of filtering any random deviations of the peaked antenna position and provides a statistically more accurate measurement of the actual antenna position. The ability of the average to follow or track long-term changes in the peaked antenna position eliminates any need to make periodic adjustments to the system.

Signal Processors Ltd.
Cambridge Science Park
Milton Road
Cambridge, CB4 4GJ
Phone (44) 223 420357
Fax (44) 223 420883

Called INTRAC™ (for Intelligent Tracking Antenna Control), Signal Processors Ltd.'s antenna control unit continually reads and stores beacon signal measurements. It then steers the antenna according to a model derived from these measurements with a tracking accuracy typically better than ±0.05 dB signal degradation. INTRAC controllers automatically detect and correct for satellite stationkeeping maneuvers and will continue to steer on memory if the beacon signal is interrupted for any reason.

Telesat International Ltd.
20122 South Molalla Ave.
Oregon City, Oregon 97045-9021
Phone (503) 656-2774
Fax (503) 632-3362
Watts (800) 331-2774

Telesat International manufactures the SyncTrack dual-axis controller along with a complete line of antennas ranging in size from 1.3 meters to 13 meters in diameter. The SyncTrack has three modes of operation: manual, step track, and program track. In the step track mode, the SyncTrack system uses the signal strength level supplied the receiver's AGC circuit to follow the movements of the satellite. If the signal level falls below a preset value, the SyncTrack ACU will make small adjustments to the satellite antenna's position to regain a peak signal level.

The SyncTrack also positions the antenna by calculating the inclined satellite's location using computer-based software programs. The antenna position is maintained until the SyncTrack determines the signal level and picture quality is about to drop below the acceptable level at which time it will move the satellite antenna to the next calculated position.

Teletronics International, Inc.
1803 Research Blvd.
Suite 404
Rockville, MD 20850-315
David J. Lee, Executive Vice President
Phone (301) 309-8500
Fax (301) 309-8851

Teletronics International, Inc. reports that it has developed a low-cost single-axis inclined orbit program pointing unit (PPU) which is suitable for antennas less than 3 meters in diameter. The PPU consists of a specially adapted mount, software, and a microprocessor that controls the actuator movements. An optional modem allows for the periodic downloading of updates to the spacecraft's orbital parameters.

TWI Systems, Inc.
1284 Geneva Drive
Sunnyvale, California 94089
Phone (408) 734-3900
Fax (408) 734-9012

TWI Systems offers the AC3 antenna control system which is comprised of an ACU and a Program Track Interface Computer. Independently, the ACU acts as a tracking receiver, antenna control unit, and personal computer capable of storing up to 100 Az/El and polarization angles as well as specific beacon

frequencies. (See photo 2-12 on page 53.)

TWI's ACU offers a variety of tracking modes, including monopulse, steptrack, and memory track. The optional Program Track Interface Computer (PTIC) adds several sophisticated computer tracking modes, such as NORAD track, INTELSAT track, Star track, Az/El/Pol track, and Smart track, which predict the current trajectory from previous tracking history.

Vertex Communications Corporation
2600 Longview Street
P.O. Box 1277
Kilgore, Texas 75662
Phone (903) 984-0555
Fax (903) 984-1826

To compliment their line of commercial satellite receiving antennas, Vertex has developed the Model 7200 Antenna Control System. The 7200's ACU provides several modes of inclined orbit tracking, including what Vertex calls Orbit Prediction Tracking (OPT). OPT incorporates fully automatic pointing to Az/EL coordinates along predicted paths derived by the 7200 ACU through application of recorded peak Az/EL step track data to a sophisticated orbital propagator. The orbital model is periodically updated by refresh data obtained during occasional step track operations. Polarization angle correction is calculated automatically and updated as required. (See photo 2-13 on page 54.)

Weston Antennas Ltd.
Dorchester, Dorset, UK DT1 1YA

Weston's "Beam Squint" tracking system is used primarily on larger antennas. Step tracking is accomplished by moving the feedhorn while the dish remains in place—effectively steering the antenna beam. In this system, the feedhorn is mounted on a rod which is attached to a universal joint. Two stepper motors—at 90 degrees to each other—act under the command of a controller which takes its tracking information from the receiver's AGC output.

Manufacturers - Antennas and Antenna Mounts

Listed alphabetically, the following manufacturers offer stand-alone mounts or antennas and mounts which can be adapted for inclined orbit satellite tracking.

Comsat Systems Division
22001 Comsat Drive
Clarksburg, Maryland 20871
Ms. Regina Rigler, Marketing Representative
Phone (301) 428-2054
Fax (301) 428-3468

Comsat's "Sure Track" three-axis mechanical tracker uses a computer printout only for initial set-up. This device mounts between the hub of the antenna and the antenna base. The antenna base provides standard positioning in azimuth and elevation for orienting the antenna toward the center of the geometric "box" that encloses the limits of satellite motion. The tracker provides an additional "nodding" motion that tracks the movement of the satellite in azimuth, elevation, and polarization rotation. It automatically adjusts itself to account for increasing satellite inclination. It can be used on antennas from 1 to 5 meters which are dedicated to receiving only one satellite. (See photo 2-2 on page 49.)

This unique mount contains no electronics and operates from a simple mechanical drive and a clock motor. A battery back-up is included—which can provide emergency power during a lengthy power failure—to preclude the need for any antenna realignment. A data sheet provides the initial settings for the time of installation.

The Sure Track mount is available in three sizes; Model ST-100 for antennas .8 to 2.0 meters in diameter, ST-300 for 2.1 to 3.4 meter antennas, and the ST-500 for antennas from 3.5 to 5 meters.

DH Satellite
600 North Marquette Road
Prairie du Chien, WI 53821
Franklin Weeks, President
Michael Doll, Vice President
Phone 608 326-8406
Fax 608 326-4233

DH Satellite manufactures both commercial and consumer grade satellite receiving systems with modified polar and Az/El mounts. (See photo 2-3 on page 49.)

Hero Communications
2290 West 8th Ave.
Hialeah, Florida 33010
Phone (305) 887-3203
Fax (305) 885-8532

Hero manufactures mesh antennas from 7 to 32 feet in diameter which can be modified for inclined orbit tracking.

Orbitron
351 S. Peterson Street
Spring Green, WI 53588
Phone 680 588-2923
Fax 608 588-2257

Orbitron manufactures mesh antennas from 2 to 7.2 meters and offers a motorized declination drive for some of the larger models. (See photo 2-6 on page 51.)

Prodelin Corporation
P.O. Box 368
Conover, N.C. 28613
Daniel Johnson, Sales & Marketing Manager
Phone 704 464-4141
Fax 704 466-0860

Prodelin offers dual axis drive mounts of several models of their commercial fiberglass antennas. (See photo 2-7 on page 51.)

Radiation Systems, Inc.
4825 River Green Parkway
Duluth, Georgia 30136
Richard Tarpley, Director of Sales and Marketing
Phone (404) 497-8800
Fax (404) 497-1009

The RSI 1.8 & 2.4 meter antennas can be ordered with motorized declination adjustment mounts.

True Focus by Andersen Manufacturing, Inc.
Rt 2, Box 434D
Idaho Falls, ID 83401
Ray Phillips, Sales Manager
Phone 208 523 6460

Universal Antenna Mfg. (Unimesh)
P.O. Box 338, Hwy. 367 North
Ward, AR 72176
Phone (501) 843-6517
Fax (501) 843-9755

Unimesh offers an International Mount with motorized elevation adjustment on its line of mesh antennas.

Photo 2-1. Astroguide offers heavy duty Az/El mounts for antennas up to 10 meters in diameter. (Photo Courtesy Astroguide).

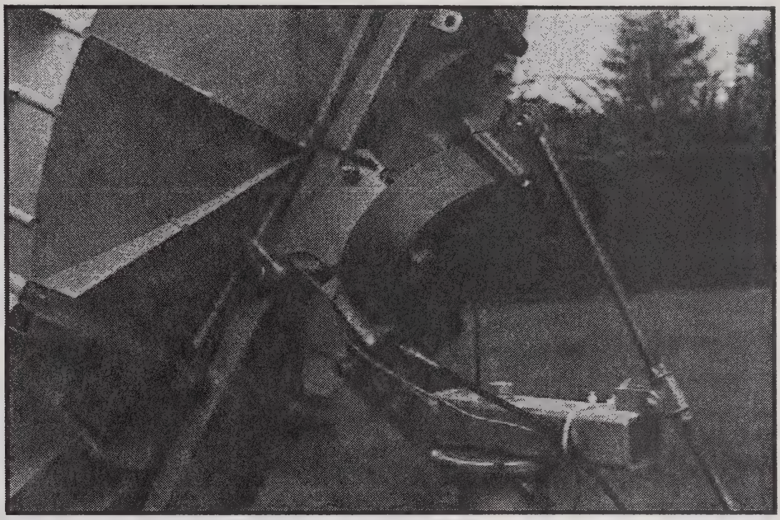


Photo 2-2. Comsat's Sure Track three-axis mechanical tracker. (Photo courtesy Comsat Corporation.)

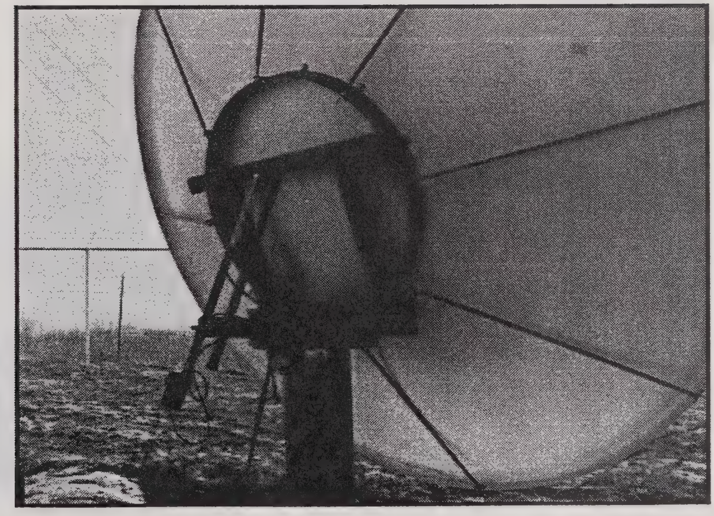


Photo 2-3. The Gibralter commercial-grade Az/El mount with a spun aluminum antenna. (Photo courtesy DH Satellite.)

Photo 2-4. The MS-1 Dual Axis Controller with a dedicated microprocessors system can store the positions of 42 satellites and track two inclined orbit satellites. (Photo courtesy Merrimac Satellite.)

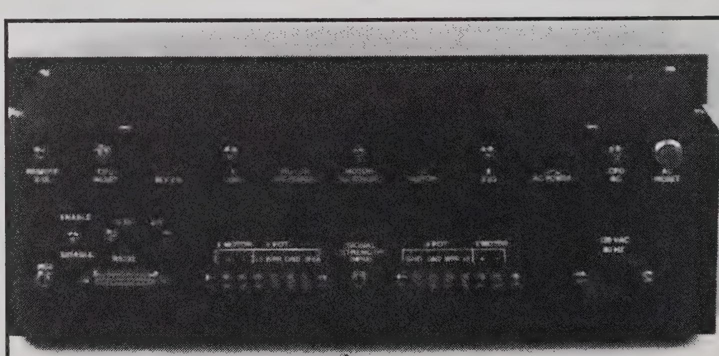


Photo 2-5. Rear panel display of he MS-1 Dual Axis Controller. (Photo courtesy Merrimac Satellite.)

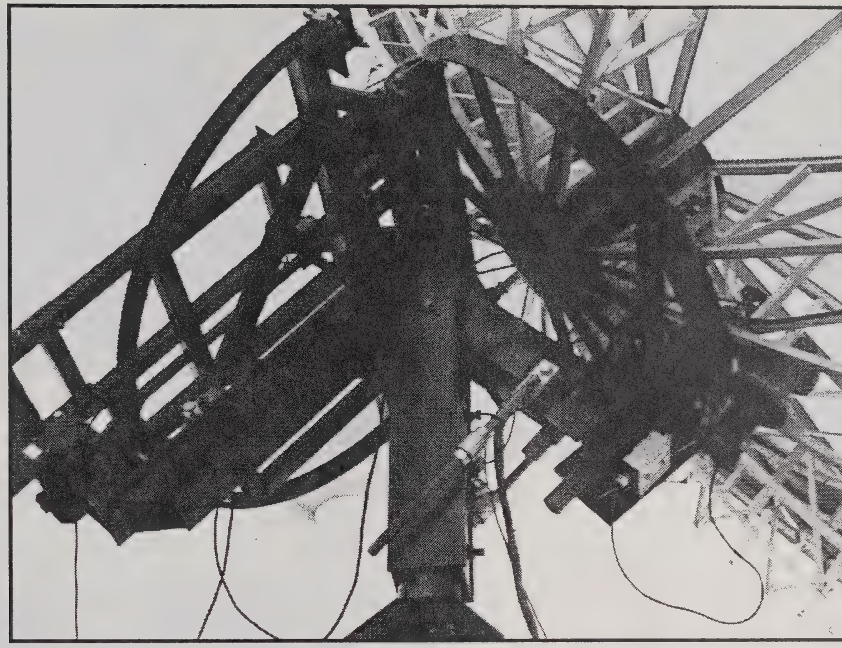


Photo 2-6. Orbitron's commercial Declination Drive package is mounted onto the antenna arm and attaches to the back of the antenna mounting structure. (Photo courtesy of Orbitron).

Photo 2-7 (right). Prodelin 2.4 meter offset Dual Axis Tracking System (Photo courtesy of Prodelin.)

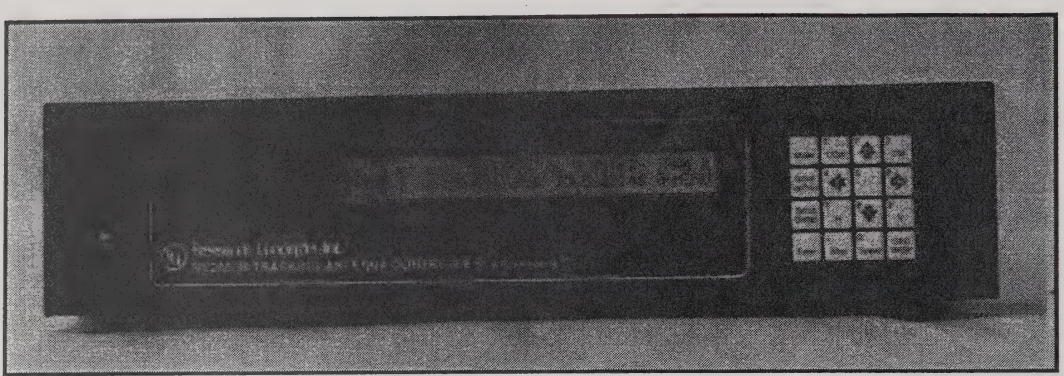


Photo 2-8. Research Concepts RC2000B Dual Axis Controller features Adapti-Drive. (Photo courtesy Research Concepts, Inc.)

Photo 2-9. Research Concepts' Smart Booster II can boost the power to both the Azimuth and Elevation motors. (Photo courtesy Research Concepts, Inc.)

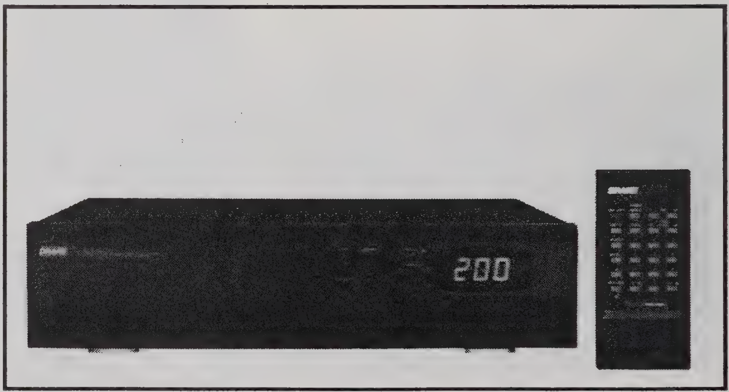


Photo 2-10. The Drake ESR 700e satellite receiver—when combined with their optional Inclined Orbit Adapter (IOA600)—can drive both Azimuth and Elevation motors, providing automatic tracking of inclined orbit satellites. (Photo courtesy R.L. Drake.)

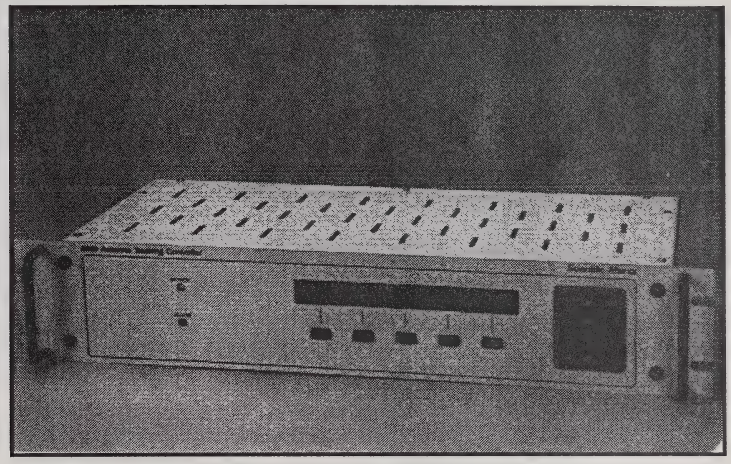


Photo 2-11. Scientific - Atlanta's 8860 Antenna Tracking Controller. (Photo courtesy Scientific - Atlanta.)

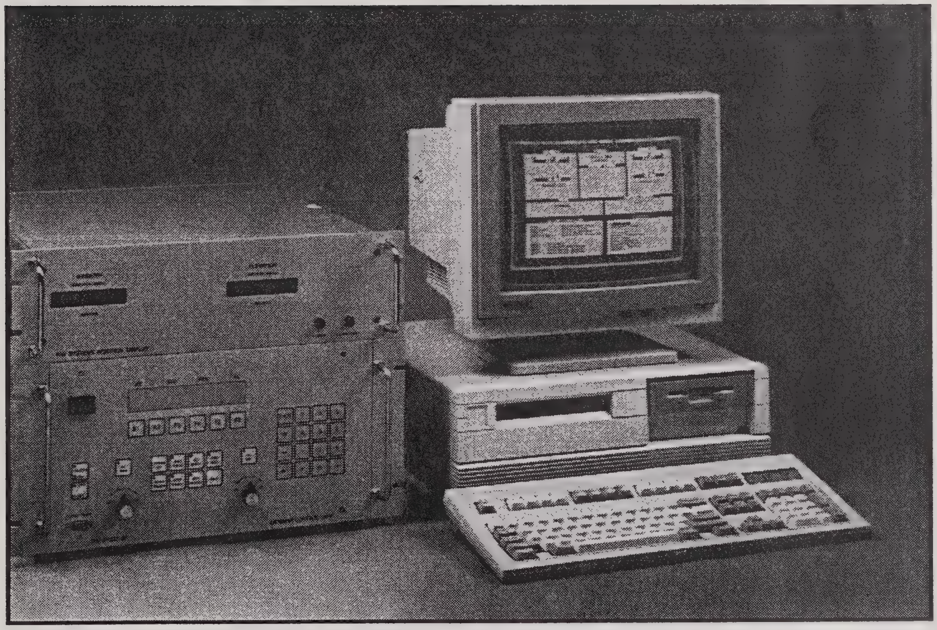


Photo 2-12. The AC3 Antenna Control Unit and optional Program Tracking Interface Computer offers a full range of operating modes. (Photo courtesy TIW Systems, Inc.)

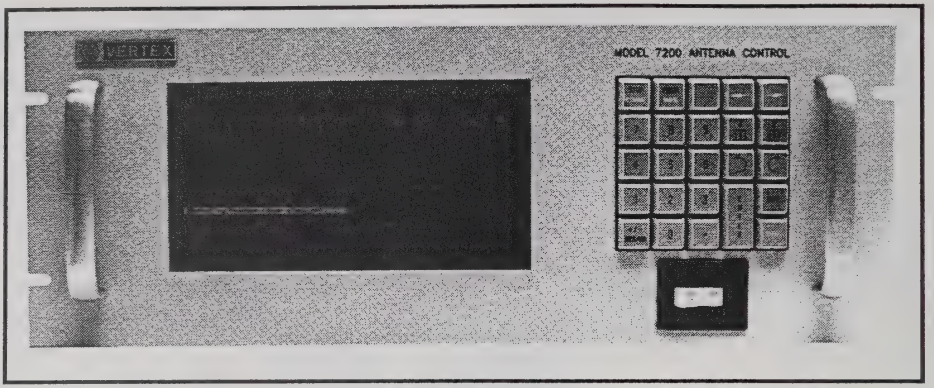


Photo 2-13. Vertex Model 7200 offers a number of operational modes including manual jog control, several programmed positioning modes, conventional step track, and their Orbit Prediction Track predictive tracking mode. (Photo courtesy Vertex.)

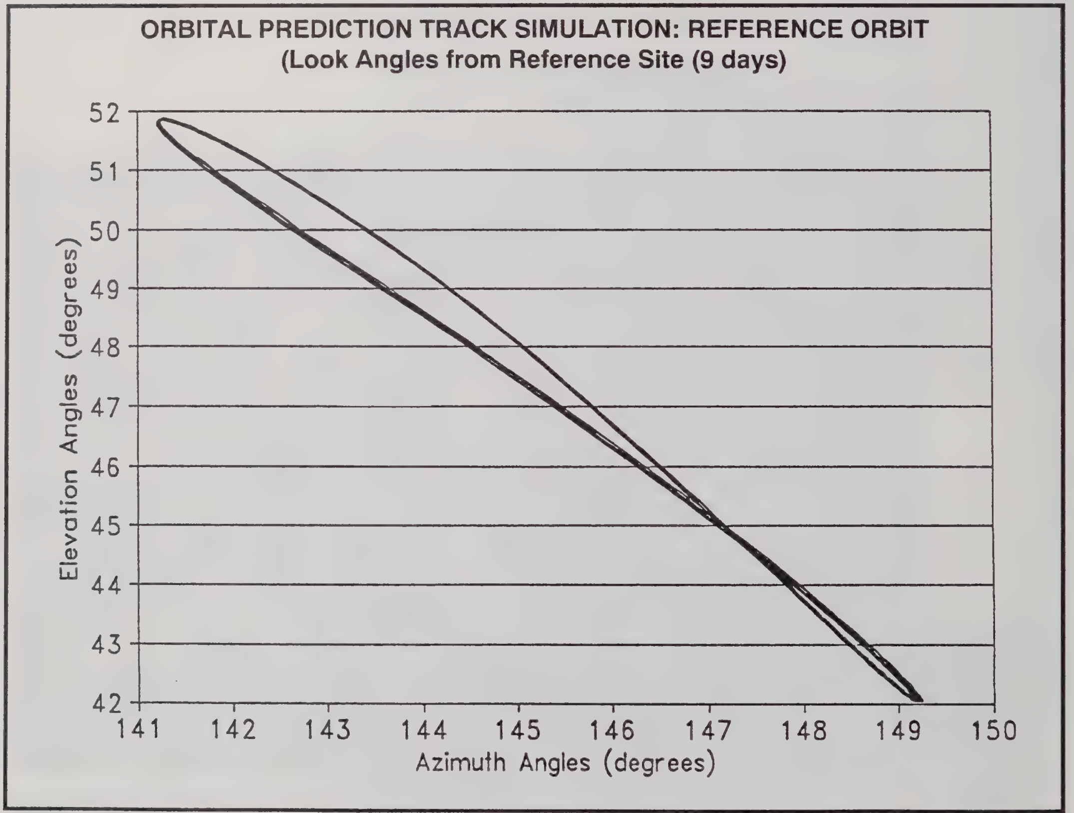


Fig. 2-13. Orbital Prediction Track Simulation. (Courtesy Vertex.)

CHAPTER THREE: REGIONAL INCLINED ORBIT SATELLITE STUDIES

South America

As of April, 1993, there were several inclined orbit satellites which could be received from locations throughout South America. Moreover, additional satellites will become available in inclined orbits during the years ahead. Table 3-1 shows the orbital locations and inclinations for these satellites.

Table 3-1. Inclined orbit satellites viewable from South America.

Satellite Name	Orbital Location	Estimated Degrees of Inclination (Beginning of Year) 1993	1994	1995	1996
INTELSAT 512	1° WEST	0.0°	0.85°	1.65°	TBR
STATSIONAR 11†	11° WEST	1.19°	2.04°	2.84°	3.64°
STATSIONAR 4†	14° WEST	0.68°	1.53°	2.33°	3.13°
INTELSAT 502	21.5° WEST	3.71°	4.56°	5.36°	6.16°
INTELSAT 504	31° WEST	3.34°	4.19°	4.99°	TBR
INTELSAT 506	50° WEST	1.78°	2.63°	3.43°	4.23°
ANIK C2	76.2° W.	1.14°	1.99°	2.79°	3.56°
ANIK C1	71.8° W.	0.0	0.0	0.0	0.0

† Russian satellites are replaced at frequent intervals and there is no guarantee that the present occupants of the Statsionar 11 (Gorizont 26) and 4 (Gorizont 20) orbital slots will remain at their current locations over the projected period. Any replacement satellites would begin operations at a lower value of inclination, increasing at a rate of approximately 0.80° per year.

TBR = To be replaced by newer satellite with full stationkeeping

Inclined Orbit INTELSAT Satellites

Due to delays in the launch of the new generation INTELSAT VII series satellites, INTELSAT is operating several INTELSAT V satellites in an inclined orbit mode to extend their orbital lifetimes and offer scarce international satellite capacity to its customers. Located at 1 degree West (359 degrees East) Longitude, INTELSAT 512 is scheduled to be placed into an inclined orbit in early 1993. This satellite will be replaced by an INTELSAT VII series spacecraft by mid-1995. At the time of writing, no unencrypted TV services were being transmitted through C-band beams covering South America and the spacecraft's Ku-band beams were directed away from South America to cover Scandinavia and Israel respectively.

Collocated at 21.5 degrees West (332.5 degrees East) Longitude with the Ku-band INTELSAT K satellite, INTELSAT 502 provides C-band services to Latin America via West hemispheric and global beams. At the time of writing, INTELSAT 502 carried a daily news feed from TV Globo New York to Rede Global in Rio de Janeiro on global beam transponder 38 [23]. INTELSAT plans to continue to operate this satellite at 21.5 degrees West Longitude in an inclined orbit mode through the end of 1996.

Positioned at 31 degrees West (329.5 degrees East) Longitude, INTELSAT 504 was not beaming any TV traffic to Latin America at the time of writing. The satellite is scheduled to continue operations at 31 degrees West Longitude until the beginning of 1995.

Located at 50 degrees West (310 degrees East) Longitude, INTELSAT 506 is scheduled to provide continuing service through the end of 1996. At the time of writing, the satellite was transmitting the full-time TV programming of Canal SUR—a Latin American cable TV service uplinked from Lima, Peru and a second Spanish-language entertainment service called GEM Television. Canal SUR's programming is comprised of news, sports and entertainment programming provided by various South American countries. The Canal SUR service, which at the time of writing was encrypted part time using the VideoCipher II Plus scrambling system, is beamed to South America via West hemispheric transponder 13[10], while GEM Television uses West hemispheric transponder 12[05].

STATSIONAR Satellites

The Russian STATSIONAR satellites are almost always operated in an inclined orbit mode, even from the very beginning of service. Although we have projected future orbital inclinations for the present occupants of the STATSIONAR 11 and 4 satellites, keep in mind that Russian satellites are replaced at frequent intervals and there is no guarantee that the present occupants of these orbital slots will remain at their current locations over the projected period. Any future replacement satellites would begin operations at a lower value of inclination, increasing at a rate of approximately 0.80 degrees per year.

At the time of writing, STATSIONAR 11 (Gorizont 26—1993) carried one full-time TV service in SECAM from Moscow in global beam transponder 6 [-1] and occasional news feeds in PAL from the Moscow Bureau of the European Broadcasting Union (EBU) in global beam transponder 9[6].

STATSIONAR 4 (Gorizont 20—1993) relays programs from RFO France and Antenne 2 to Madagascar in SECAM and transmit TV Madagascar in SECAM through global beam transponder 7[1]. Global beam transponder 9[6] is used in the mornings (South American time) to transmit news feeds in SECAM for various Eastern European TV organizations and in the evenings to transmit several hours of Cuban TV in NTSC.

ANIK C1 & C2

On January 19, 1993, Telesat Canada announced that PARACOM S.A. of Argentina had contracted for the use of the Ku-band Anik C1 and Anik C2 satellites for interim domestic service. The final operating agreement for the new system was signed by both parties on April 28, 1993. Under terms of the argreement, Telesat and PARACOM S.A. have established a corporation, PARACOMSAT, to which they have transferred their respective ownership of interests (10% for Telesat and 90% for PARACOM) in the two satellites. PARACOM S.A., headquartered in Buenos Aires, is a new company established specifically to invest in a satellite communications system. It is owned by 8 Argentinean companies.

Because the capacity of both satellites has largely been contracted for, the both the Argentinean investors and Telesat are reasonably sure of the overall success of the joint project. The two satellites primarily will be used for television dstribution, with the balance of capacity used for telephone and data services. Both satellites will provide excellent signal coverage in the most populated areas of Argentina, as well as Chile and Uruguay.

Under terms of the agreement, Anik C1 was inverted and relocated to a new Argentiniean orbital slot of 71.8 degrees West Longitude, arriving on April 15, 1993. (The satellite will be inverted to maximize antenna pointing for service to Argentina). Anik C2 subsequently will be relocated to a second Argentinean location of 76.2 degrees West Longitude. This satellite is expected to arrive on station by mid-June 1993. Between the two satellites it is expected that a total of 23 transponders will be available for service.

Each Anik C satellite carries sixteen Ku-band transponders, eight transmitting in an East or East-Central Beam or a combined East/East-Central Beam, and eight transmitting in a West- or West-Central Beam or a combined West/West-Central Beam. So why is the total number of transponders for the system limited to 23?

In order for Telesat to provide TT&C for the two satellites from outside the new footprint area covering Argentina, one transponder must be shut off in each satellite so that its TWTA can be used for transmitting telemetry through each spacecraft's omnidirectional TT&C antenna. Anticipated reductions in solar panel efficiency over each satellite's mission lifetime also means that an additional transponder will be lost to each satellite. Finally, to maximize East-West stationkeeping fuel efficiency, the exterior solar panels on each spacecraft can be retracted to change the satellite's center of gravity. While this marginally increases fuel efficiency, it also reduces the solar electric generating ability of each spacecraft by another two transponders each.

The Transition to Nahuel. The Anik C1 and Anik C2 satellites will be used as an interim system until the permanent Argentinean satellite system, Nahuel, is operational in 1996. Nahuel satellites have been registered with the IFRB at the orbital locations of 80 and 85 degrees West Longitude.

When the satellites are inverted to cover a new location below the Earth's equator, the satellite footprint coverage zones also will be inverted. From the projected maps shown on page 61, one can see that a single Anik C satellite does not have a wide enough beam to provide coverage of the entire country. However, it may be possible to have a different boresight for each Anik C satellite so that one spacecraft's beams would cover the Northern area of the country while the other would cover the Southern area of Argentina.

It is anticipated that Argentina will use the quarter-Canada East Central and West Central beams for coverage because of their higher power levels and their overlapping nature providing the widest possible coverage of the heartland of Argentina. However, readers are cautioned that the maps shown below are speculative only because no data on spacecraft antenna boresight had been released at the time of writing.

With the successful launch and deployment of the Anik E1 and Anik E2 satellites for Canada in 1991, the Ku-band Anik C1 and Anik C2 satellites were no longer required for service continuity. Anik C1 was launched in 1985 and placed in a storage orbit for several years, coming into use during the transition to the Anik E satellites as part of traffic transfer operations. Anik C1 currently has about 4.5 years of operating fuel left on board. Anik C2, launched in 1983, is now in inclined orbit, an operating mode that extends fuel life but limits the type of traffic the satellite can carry. Anik C2 is capable of providing service to the end of 1996.

A History of the Anik C Program. Since their launch in the mid-1980s, Anik C satellites have provided coverage of virtually all of populated Canada by means of four spot beams focussed on the Western, West-central, East-central, and Eastern regions of the country. Signals can be transmitted through any single beam, or through combined West and West-central or East and East-central beams.

Anik C3 was launched on November 11, 1982. The satellite continues to provide telecommunications services on behalf of Telesat Canada from 114.9 degrees West Longitude. As of January 1993, the satellite had attained an orbital inclination of 1.21 degrees.

On June 11, 1983, Anik C2 was launched from the cargo bay of the NASA space shuttle *Challenger*. The satellite initially was leased to GTE for a quasi-DBS service serving U.S. households. Anik C2 was positioned at 105 degrees West Longitude and had its beams tilted South to better illuminate the Northern half of the United States. USCI, GTE's DBS customer, went out of business in May of 1984 and the satellite subsequently was relocated to 112.5 degrees West Longitude where it provided Telesat Canada with a variety of telecommunications services through 1991. Following the successful launch of Anik E2 and E1, Anik C2 was relocated to 109 degrees West Longitude and placed in an inclined orbit. As of January 1993, Anik C2 had an orbital inclination of 1.14 degrees.

On April 12, 1985, Anik C1 was launched from a NASA space shuttle to an

inactive orbital location at 107.5 degrees West Longitude. Telesat left the satellite in a special storage orbit for a three-year period in order to conserve stationkeeping fuel and extend the conventional mission lifetime of the satellite in geostationary orbit through April of 1997.

Telesat 's Anik C1, the third of three Anik C satellites built by Hughes Aircraft for the Canadian organization, was always considered spare capacity that served as an in-orbit back-up for the system. In 1986, Telesat Canada entered into an agreement governing the sale of Anik C1 to an unidentified company. However, the sale fell through when the prospective purchaser defaulted on the payment schedule.

At one point, Telesat intended to use Anik C1 to establish a joint venture company that would provide Ku-band direct-to-home satellite TV services within Canada. However, the company abandoned its plans because Canadian investors from the broadcast and cable TV industries there turned down offers for equity participation in the project. According to Telesat , the Anik C1 spacecraft was capable of "...delivering a high quality signal with adequate power to service private homes that are equipped with parabolic antennas approximately 1 meter (3.28 feet) in diameter".

In 1991, Telesat launched two dual-band Anik E satellites; these two satellites replaced Canada's previous generation of C-band Anik D and Ku-band Anik C satellites. Since Anik E1 & E2 currently supply all of the telecommunications needs of Canada, both C and Ku-band, the Ku-band Anik C1 & C2 satellites were no longer needed and subsequently were sold to PARACOM and relocated to new orbital assignments.

Table 3-2: Anik C1 & C2 at a Glance

Operational History		
Launch Date:	C1: April 13, 1985	
	C2: June 11, 1983	
Orbital Assignments:	C1: 71.8° West	
	C2: 76.2° West	
Launch Vehicle:	NASA STS	
Status:	Operational domestic satellites	
Design Life:	10 years †	
† (lifetime of Anik C1 was extended through use of storage orbit)		
Communications Payload		
Frequency Band(s):	Receive:	14.000~14.500 GHz
	Transmit:	11.700~12.200 GHz
Channels:	16 transponders	
Channel Bandwidth:	54 MHz	
Signal Power (EIRP):	46.5 dBW nominal within coverage area	
Antenna Coverage:	four narrow spot beams or	
	two combined beams of two spots each	
TWTA Power:	15 watts	
Capacity:	24 simultaneous color TV signals or	
	16,128 one-way voice channels *	

Table 3-2 continued: Anik C1 & C2 at a Glance

Anik C Spacecraft	
Satellite Type:	Hughes Aircraft HS 376 spin-stabilized
Initial On-Station Weight:	632kg (1,393.3 lbs)
Maximum Deployed Dimensions:	6.43m (21.1 ft) in height, 2.18m (7.2 ft) in diameter
Electrical Power:	1,135 watts

* Reduced capacity due to expanded TT&C requirements and solar array modification

The spacecraft's initial on-station weight was 567 kg (1,250 lbs.), of which 100 kg (220 lbs.) was the initial in-orbit propellant. Design life of each satellite in orbit is 10 years. Stationkeeping and attitude control are provided by four Hughes 5-pound thrusters.

The Antenna Platform. The transmit and receive beams are created by a 183cm (72 inch) reflector with two reflecting surfaces. One surface is sensitive to vertical polarization and the other to horizontal. Separate microwave feed networks are used for the different polarizations.

Anik C satellites covered Canada using four spot beams for the downlink and an All-Canada beam for the uplink. Two pairs of spot beams, each 1° x 2° in beamwidth, were employed. The downlink band was used twice, the Western beam pair radiated with vertical polarization, and the Eastern pair horizontal. Within each half of the country, the output of each TWTA amplifier may be selected to either of the two quarter-country spot beams serving that polarization, or may be divided equally between them, giving a half-country (1° x 4° approximately) beam.

Transponder Frequency Plan. Each Anik C satellite carries sixteen 54-MHz-wide transponders which uplink in the 14.0 GHz and downlink in the 11.7 to 12.2 GHz frequency bands. Each of these 16 transponders are capable of carrying two full color analog TV signals, together with their associated audio and cue and control circuits, for a maximum total TV signal capacity of 32 analog TV programs per satellite. This capacity may be multiplied through the use of digital video compression.

EIRP Optimization Techniques. Telesat's preferred method of operating an Anik C satellite for video distribution was to have two TV channels (24 MHz wide each) share occupancy of each 54 MHz transponder. This was achieved by offsetting the two TV carriers by plus and minus 13 MHz from transponder center frequency. Since the frequency reuse mode offsets vertical and horizontal channels by the same 13 MHz, it interleaves the cross-polarized TV signals in such a way that carrier frequency on one polarization falls in a gap in the frequency spectrum of the opposite polarization, thus providing an extra measure of protection against interference.

The power sharing involved in the half-transponder analog TV configuration is a major disadvantage because the TWTA's 15-watt output has to be

split between two carriers (-3 dB loss) and also backed off by a further 2 dB minimum to control the degree of intermodulation between the two TV carriers sharing the transponder. This was in addition to the 3 dB EIRP reduction involved in using the combined East/East central or West/West-central beams instead of one of the quarter Canada beams. While in theory full channel TV in one quarter-Canada spot beam would provide an EIRP of 48 dBW EIRP, the reality of dual-channel TV in a combined half-Canada beam provides an EIRP of just 39.5 dBW.

A more effective use of the capacity, even for analog TV transmission, would be to use full-transponder power in a standard 36 MHz TV channel (transponder usable bandwidth is 54 MHz), and with that power feeding a single spot beam, beam center EIRP could be expected to exceed 53 dBW. In this mode an antenna of less than one meter aperture could provide adequate DBS reception at beam center. In the combined beam mode, EIRP is reduced by some 3 dB, which would require TVRO antennas ranging from 1.2 to 1.8 meters in diameter within the primary contour areas.

FIG. 3-1. Hypothetical East-Central/West-Central beam coverage of Argentina via Anik C.

North America and the Caribbean

As of April, 1993, there were several inclined orbit satellites which could be received from locations throughout North America and the Caribbean. Moreover, additional satellites will become available in inclined orbits during the years ahead. Table 3-3 shows the orbital locations and inclinations for these satellites.

Table 3-3. Inclined orbit satellites viewable from North America and the Caribbean.

Satellite Name	Orbital Location	Estimated Degrees of Inclination (Beginning of Year) 1993	1994	1995	1996
INTELSAT 512	1° WEST	0.0°	0.85°	1.65°	TBR
STATSIONAR 11†	11° WEST	1.19°	2.04°	2.84°	3.64°
STATSIONAR 4†	14° WEST	0.68°	1.53°	2.33°	3.13°
INTELSAT 502	21.5° WEST	3.71°	4.56°	5.36°	6.16°
INTELSAT 504	31° WEST	3.34°	4.19°	4.99°	TBR
INTELSAT 506	50° WEST	1.78°	2.63°	3.43°	4.23°
GSTAR 3 ¥	93° WEST	4.56°	5.91°	6.71°	7.51°
SBS 4	77° WEST	—	0.85	1.65	2.45
SBS 3 *	77° WEST	1.16°	2.01°	2.81°	3.61°
SBS 2 **	77° WEST	4.36°	5.21°	6.01°	6.81°
ANIK C3	114.9° W.	1.21°	2.06°	2.86°	3.46°
INTELSAT 503	177° WEST	3.35°	4.20°	TBR	TBR
INTELSAT 510	177° WEST	——	——	2.15°	2.95°
INTELSAT 508	180° WEST	1.46°	2.31°	3.11°	3.91°
INTELSAT 511	177° EAST	0.00°	0.85°	TBR	TBR
INTELSAT 510	174° EAST	0.40°	1.35°	TBR	TBR

† Russian satellites are replaced at frequent intervals and there is no guarantee that the present occupants of the Statsionar 11 (Gorizont 26) and 4 (Gorizont 20) orbital slots will remain at their current locations over the projected period. Any replacement satellites would begin operations at a lower value of inclination, increasing at a rate of approximately 0.80° per year.

¥ It is unlikely that GTE SPACENET will continue to operate GSTAR 3 once the satellite's inclination has exceeded ±6.0 degrees.

* SBS 3 will be relocated to 77 degrees West Longitude following the successful launch of Galaxy IV-H in June of 1993.

** SBS 2 will be relocated to 77 degrees West Longitude following the successful launch of Telstar 401 in December of 1993.

TBR = To be replaced by newer satellite with full stationkeeping

Readers may refer to the entries of the STATSIONAR and Atlantic Ocean Region INTELSAT satellites previously presented in the Case Study for South America for details on satellite operations and available TV programming. Figure 3-3 shows the limits of visibility for the available Atlantic and Pacific Ocean INTELSAT satellites.

INTELSAT Pacific Ocean Region Satellites

INTELSAT 510 is scheduled to be replaced at 174 degrees East Longitude by a new INTELSAT VII series satellite in early 1994. INTELSAT 510 will then be relocated to 177 degrees West (183 degrees East) Longitude. At the time of writing, INTELSAT 510 carried two TV news feed channels on global beam transponder 38 [23] and 38 [24].

INTELSAT 511 is scheduled to be replaced at 177 degrees East Longitude by a new INTELSAT VII series satellite in mid 1994. INTELSAT 511 will then be relocated to 31 degrees West (329 degrees East) Longitude to replace INTELSAT 504 in early 1995.

INTELSAT 508 will be replaced by an INTELSAT VII series satellite at 180 degrees East Longitude by early 1996. Relocation plans for INTELSAT 508 have not yet been announced. At the time of writing, INTELSAT 508 relayed TV programs in NTSC for NHK Tokyo via global beam transponder 35 [18], RFO France TV programs to Tahiti in SECAM via global beam transponder 36 [20], U.S. broadcast TV network programs to Nine Network Australia via global beam transponder 37 [22], and two news feed channels for TV New Zealand via global beam transponder 38 [23] and 38 [24].

SBS 4, SBS 3 & SBS 2

On January 8, 1993, Hughes Communications Galaxy, Inc. (HCG) requested that the Federal Communications Commission modify the license for the SBS-4 satellite to permit HCG to cease North-South stationkeeping and to operate SBS-4 in an inclined orbit mode. HCG will continue to perform the required East-West station-keeping of ±.05 degrees.

Previously operating at the 91 degrees West Longitude orbital location, SBS 4 has been replaced by Galaxy VII(H), which was successfully launched in October, 1992. HCG has recently been authorized to move SBS-4 to the 77 degrees West Longitude orbital location, where it will operate for the remainder of its useful life.

HCG intends to use the SBS-4 satellite for a variety of purposes. First and foremost, SBS-4 will continue to serve as a back-up for other satellites in HCG's fleet of Ku-band satellites. Second, HCG will make SBS-4 available for new customers, which may include applications requiring use of large tracking antennas or short satellite feeds, such as satellite news gathering operations. Third, SBS-4 ultimately may be made available for use as a foreign domestic satellite. The latter use would require repositioning, which would consume substantial amounts of fuel.

The present request for authority to operate SBS-4 in an inclined orbit is intended to conserve fuel. This would not only prolong the life of the satellite, but also would preserve the value of the satellite for future uses which themselves may require significant fuel resources.

At present, it is expected that the satellite's useful life geostationary will extend only to 1994. Because North/South stationkeeping consumes over 90 percent of total fuel requirements for station operation, inclined orbit

mode would extend the useful life of SBS-4 for several years.

In the event that Commission action on this application is not possible before SBS-4 is moved to the 77 degrees West Longitude orbital location, HCG also has requested, by separate application, Special Temporary Authority to operate SBS-4 in an inclined orbit mode.

Two additional SBS satellites, SBS 2 and SBS 3, also will be relocated to 77 degrees West Longitude in 1993. These satellites will be maintained as spares in the event of a failure of any other Ku-band satellite in the Hughes Communications Galaxy system.

GSTAR 3

GTE SPACENET's GSTAR 3 satellite has been operated in an inclined orbit since its launch in September of 1988, when the failure of the spacraft's apogee kick motor placed the satellite in a lower-than-normal insertion orbit. GTE subsequently was forced to burn precious stationkeeping fuel during a total of 166 maneuvers to nudge the wayward satellite into the geostationary arc. Since the time of launch, GSTAR 3 has been operated in an inclined orbit mode to extend its operational lifetime. GTE developed special antenna tracking systems to allow its customers to use the satellite. At the time of writing, TV transmissions were handled sporadically by the spacecraft. GTE SPACENET is not expected to continue to operate the spacecraft once its orbital inclination exceeds ±6 degrees.

ANIK C3

With the successful launch of Anik E1 and E2 in 1991, Anik C3 was placed in an inclined orbit at 114.9 degrees West Longitude. At the time of writing, the satellite was serving as an in-orbit spare. In this role, the spacecraft is used to relay TV programs very infrequently.

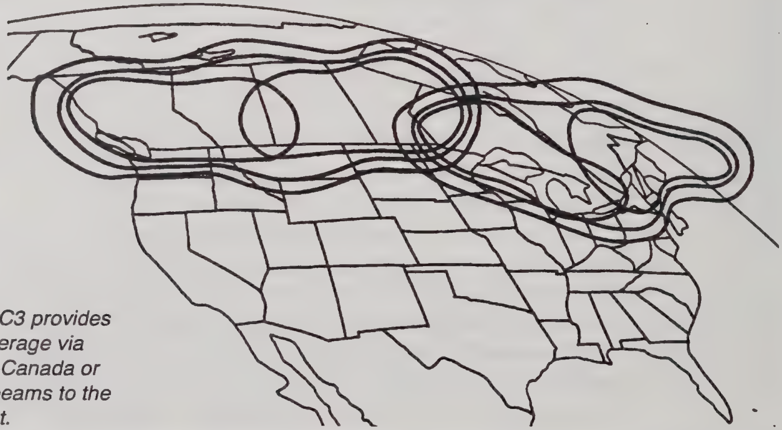


FIG 3-2. Anik C3 provides Canadian coverage via either quarter-Canada or half-Canada beams to the East and West.

Asia, Australia and the Pacific Rim

As of early 1993, there were several inclined orbit satellites which could be received from Asia and the Pacific Rim. Moreover, additional satellites will begin using inclined orbits during the years ahead. Table 3-4 shows the orbital locations and inclinations for these satellites.

Table 3-4. Inclined Orbit satellites viewable from Australia and the Pacific Rim.

Satellite Name	Orbital Location	Estimated Degrees of Inclination (Beginning of Year) 1993	1994	1995	1996
INTELSAT 503	177° WEST	3.35°	4.20°	TBR	TBR
INTELSAT 510	177° WEST	——	——	2.15°	2.95°
INTELSAT 508	180° WEST	1.46°	2.31°	3.11°	3.91°
INTELSAT 511	177° EAST	0.00°	0.85°	TBR	TBR
INTELSAT 510	174° EAST	0.40°	1.35°	TBR	TBR
OPTUS A2	164° EAST	0.0°	0.85°	1.65°	2.45°
STATSIONAR 7†	140° EAST	1.53°	2.38°	3.18°	3.98°
PALAPA PAC.	134° EAST	2.33°	3.18°	3.98°	TBD
RIMSAT 1	134° EAST	TBD	TBD	TBD	TBD
RIMSAT 2	130° EAST	TBD	TBD	TBD	TBD
SPACENET I	115.5° EAST	0.00°	0.00°	TBD°	TBD°
COMSTAR D4	TBD	6.10°	6.95°	7.75°	TBR
STATSIONAR 21†	103° EAST	0.90°	1.75°	2.55°	3.35°
STATSIONAR 14†	96° EAST	1.42°	2.27°	3.07°	3.87°
INTELSAT 501	91.5° EAST	4.26°	5.11°	5.91°	6.81°
STATSIONAR 6†	90° EAST	0.39°	1.24°	2.04°	2.84°
TDRS 1	85° EAST	6.74°	7.59°	TBR	TBR
STATSIONAR 3†	85° EAST	0.49°	1.44°	2.24°	3.04°
STATSIONAR 13†	80° EAST	0.55°	1.35°	2.15°	2.95°
INTELSAT 505	66° EAST	2.79°	3.64°	4.44°	TBR
INTELSAT 507	57° EAST	2.38°	3.23°	4.03°	TBR

† Russian satellites are replaced at frequent intervals and there is no guarantee that the present occupants of the Statsionar 21 (Gorizont 18), Statsionar 14 (Gorizont 19), Statsionar 6 (Gorizont 21), Statsionar 3 (Raduga 26), and Statsionar 13 (Gorizont 24) orbital slots will remain at their current locations over the projected period. Any replacement satellites would begin operations at a lower value of inclination, increasing at a rate of approximately 0.80° per year.

TBR = To be replaced by newer satellite with full stationkeeping

TBD = To be determined following inception of service in early 1993.

INTELSAT Pacific Ocean Region Satellites

INTELSAT 510 is scheduled to be replaced at 174 degrees East Longitude by a new INTELSAT VII series satellite in early 1994. INTELSAT 510 will then be relocated to 177 degrees West (183 degrees East) Longitude. At the time of writing, INTELSAT 510 carried two TV news feed channels on global beam transponder 38 [23] and 38 [24].

INTELSAT 511 is scheduled to be replaced at 177 degrees East Longitude

by a new INTELSAT VII series satellite in mid 1994. INTELSAT 511 will then be relocated to 39.5 degrees West (320.5 degrees East) Longitude to replace INTELSAT 504 in early 1995. At the time of writing, INTELSAT 511 carried two TV news feed channels on global beam transponder 38 [23] and 38 [24].

INTELSAT 508 will be replaced by an INTELSAT VII series satellite at 180 degrees East Longitude by early 1996. Relocation plans for INTELSAT 508 have not yet been announced. At the time of writing, INTELSAT 508 relayed TV programs in NTSC for NHK Tokyo via global beam transponder 35 [18], RFO France TV programs to Tahiti in SECAM via global beam transponder 36 [20], U.S. Network programs to Nine Network Australia via global beam transponder 37 [22], and two news feed channels for TV New Zealand via global beam transponder 38 [23] and 38 [24]. West hemispheric beam traffic included ESPN International, U.S. network feeds to Networks 7, 9 and 10 Australia, KDD/Keystone's Skylink feed channel, CNN International. On Ku-band the satellite's East spot beam was supplying news feeds to Japan's Fuji TV and Tokyo Broadcasting System.

As noted above, INTELSAT 503 will be replaced by INTELSAT 510 in 1994. At the time of writing, INTELSAT 503's Ku-band East spot beam was relaying news feeds from the U.S. on behalf of Japan's TV Tokyo, NTV, and TV Asahi.

INTELSAT Southeast Asia Satellite

A new fourth region, in addition to the three regions currently served by INTELSAT, has been established to supply much needed capacity for customers in Southeast Asia. At the time of writing, INTELSAT 501 was drifting towards 91.5 degrees East Longitude from its previously assigned location over the Pacific Ocean. The satellite is expected to enter service at its new orbital position in the first quarter of 1993. No information concerning possible TV traffic has been released to date.

INTELSAT Indian Ocean Region Satellites

INTELSAT 505 at 66 degrees East Longitude is scheduled to be replaced by a new generation INTELSAT VII satellite by mid-1995. At the time of writing, the satellite's C-band capacity was providing TV transmissions for Worldnet on global beam transponder 38 [24] and for RTM2 Malaysia on Northeast zone beam transponder 52 [06] .

INTELSAT 507, currently located at 57 degrees East Longitude, is scheduled to be replaced by INTELSAT 512 in 1995. The satellite transmits international news feeds on global beam transponder channels 38 [23] and 38 [24]. Two Bangkok TV channels also use the satellite's East zone beam to reach TV stations in Thailand.

STATSIONAR Satellites

The Russian STATSIONAR satellites are almost always operated in an inclined orbit mode, even from the very beginning of service. Although we have projected future orbital inclinations for the present occupants of the

various STATSIONAR satellites available within the region, keep in mind that Russian satellites are replaced at frequent intervals and there is no guarantee that the present occupants of these orbital slots will remain at their current locations over the projected period. Any future replacement satellites would begin operations at a lower value of inclination, increasing at a rate of approximately ±0.80 degrees per year.

At the time of writing, STATSIONAR 7 (Gorizont 18—1993) at 140 degrees East Longitude carried two full-time TV services in SECAM from Moscow in spot beam transponder 6 [-1] and North hemispheric beam transponder 10[9].

STATSIONAR 21 (Gorizont 25—1993) at 103 degrees East Longitude carries one full-time TV service in SECAM from Moscow in spot beam transponder 6 [-1], TV Azerbaidjan on North hemispheric beam transponder 10[9]. Asia TV TWO (Sun TV), a Tamil-language service in PAL, also is expected to start operations in the near future on this satellite.

STATSIONAR 14 (Gorizont 19—1993) at 96.8 degrees East Longitude carries one full-time TV service in SECAM from Moscow in spot beam transponder 6 [-1], China's CCTV-4 in PAL on global beam transponder 9[6], and Asia TV Gold, a Hindi- and English-language service, in PAL on North hemispheric beam transponder 10[9].

STATSIONAR 6 (Gorizont 21—1993) at 90 degrees East Longitude carries three full-time TV services in SECAM from Moscow in spot beam transponder 6 [-1], North hemispheric beam transponder 10[9], and global beam transponder 11[11].

STATSIONAR 3 (Raduga 26—1993) at 85 degrees East Longitude carries a single TV service in PAL called "Ahmadiyya Muslim TV" which airs on Fridays and Saturdays.

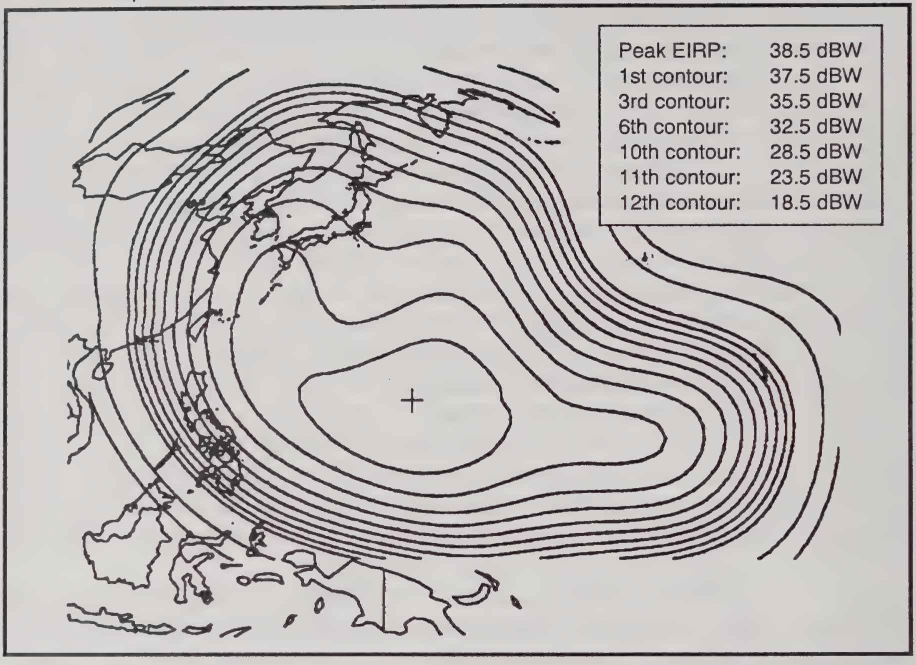
STATSIONAR 13 (Gorizont 24—1993) at 80 degrees East Longitude carries one full-time TV service in SECAM from Moscow in spot beam transponder 6 [-1] and Intersputnik TV regional feeds on North hemispheric beam transponder 10[9].

Palapa Pacific

The Signatory of the United States has initiated consultation with INTELSAT concerning the proposed use of the Palapa Pacific-1 satellite network at one of the alternative orbital locations of 134, 139, or 144 degrees East Longitude for the provision of domestic public telecommunications services within U.S. territories. The Palapa Pacific-1 satellite is planned to become operational on August 1, 1992, with the expected lifetime of between five and seven years. The maximum proposed inclination tolerance is ± 5.0 degrees.

According to the Signatory of Indonesia, ownership of the Palapa B-1 satellite has been transferred to an Indonesian private company, PT Pasifik Satellit Nusantara, which will operate Palapa B-1 as Palapa Pacific-1. PSN shareholders include PT Telekomunikasi Indonesia, the state owned telecommunications company and PT Elektrindo Nusantara, a subsidiary of PT

FIG. 3-3. Palapa Pacific satellite coverage zone.



Bimantara Citra—one of the prominent large business groups in Indonesia.

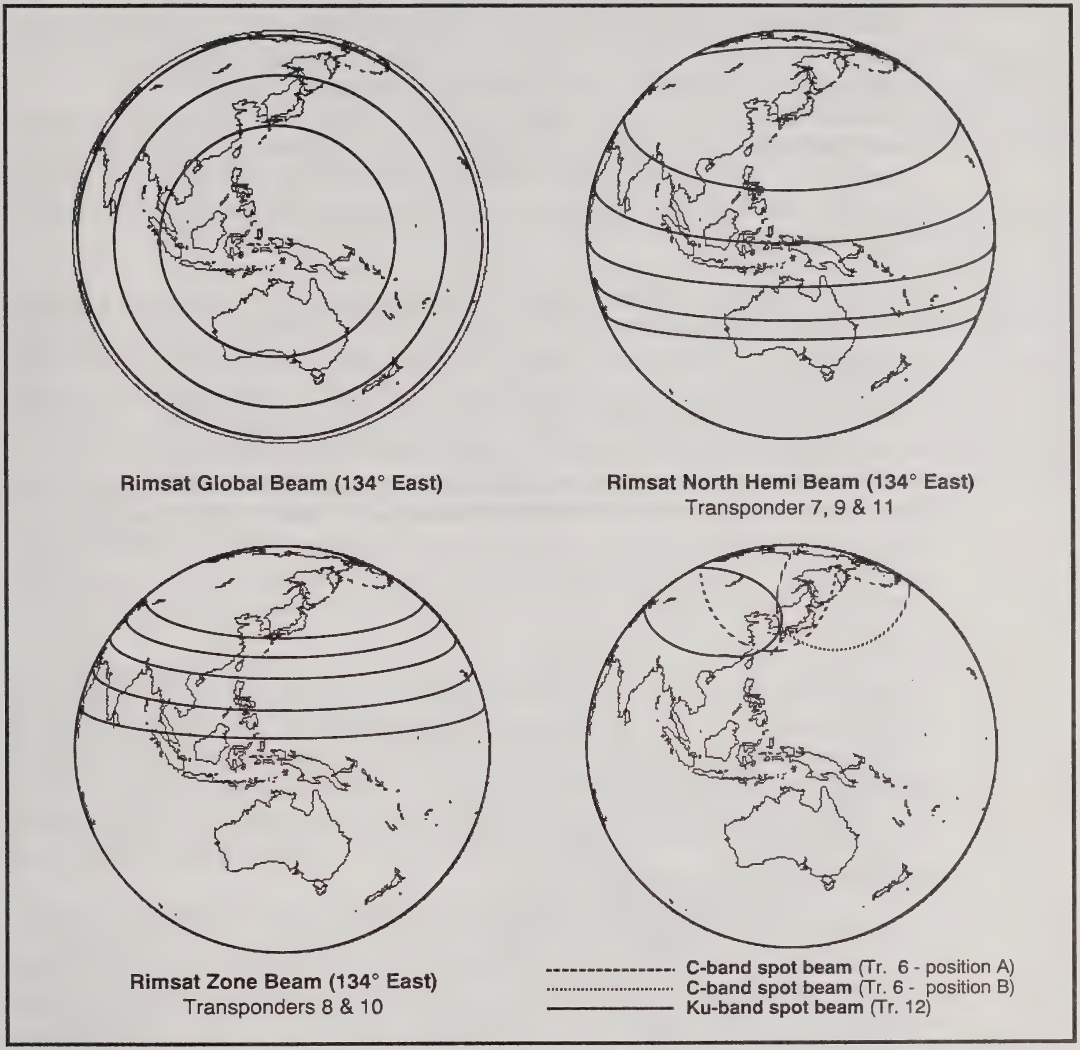
In 1992, the Signatory of Indonesia initiated consultation with INTELSAT concerning the proposed use of the Palapa Pacific-1 satellite for the provision of domestic public telecommunications services within Indonesia. The Palapa Pacific system initially will use the aging Palapa B1 satellite in an inclined orbit mode from 134 degrees East Longitude. A total of 22 transponders will be available for telecommunications and broadcast TV, while two will be allocated for TT&C purposes. Palapa B1 had an estimated lifetime of about four more years in inclined orbit starting from August of 1992. Palapa B2P will replace Palapa B1 at 134 degrees East Longitude by mid-1995 and provide a continuation of Palapa Pacific Services until the year 2000 in an inclined orbit mode. Moreover, the Republic of Indonesia has filed for two additional orbital locations for future Palapa Pacific satellites: 139 and 144 degrees East Longitude.

Finally, when the next generation Palapa C satellites arrive in mid-1995, the two spacecraft will each carry a "Pacific" payload to support future PSN services. This capacity will be geostationary rather than inclined.

The Rimsat Satellite System

On November 12, 1992, Rimsat of Fort Wayne, Indiana entered into an agreement with the Russian Space Agency to acquire a minimum of two in-orbit Russian communications satellites—one Gorizont and one Raduga—

FIG. 3-4. Rimsat satellite coverage zones.



in order to market international satellite services in Southeast Asia and the Pacific Rim beginning in the second quarter of 1993. In April of 1992, Rimsat had entered into an agreement with Tongasat to use two orbital locations, 134 and either 130 or 142.5 degrees East Longitude, which previously had been licensed by Tongasat with the International Frequency Registration Board.

Rimsat expects to offer a total of three "Raduga" transponders by early second quarter of 1993, then to add four more "Gorizont" transponders prior to the end of 1993 for a total of seven C-band satellite transponders. The

initial two Russian satellites will be operated in an inclined orbit mode. If the initial Rimsat offerings prove to be successful, Rimsat intends to purchase additional hybrid Gorizont and Ku-band "Express" satellites with full geostationary capabilities from the Russian Space Agency.

Rimsat intends to offer a variety of international and domestic satellite telecommunications services via its Russian satellites, including TV distribution and VSATs for business communications. According to recent reports, TT&C for the Russian satellites will be handled by the Russian Space Agency.

Future Rimsats To Use A Reverse Inclined Orbit? According to recent comments made by Tongsat's founder Dr. Matt Nilson, future Gorizont satellites launched expressly for the Rimsat system could make use of a kind of "reverse" inclined orbit which to date has been used by satellite operators (such as Telesat Canada for Anik C1) as a "storage orbit". This storage orbit, which can only be implemented at the time of launch, has been calculated to take advantage of all natural forces impinging on the satellite—including solar winds and the effects of the gravitational fields of the Earth and Moon—so that, as time goes on, the inclination lessens without requiring any expenditure of stationkeeping fuel. At some particular point in time the amount of diurnal inclination for the satellite will reach 0 degrees or actual geostationary operation.

Whenever the reverse inclined orbit has been used for storage purposes, the satellite is placed into regular service once it has attained the geostationary subsatellite point. The main advantage is that the satellite will retain all of the stationkeeping fuel initially loaded into the spacecraft prior to launch. It also is much cheaper to store a satellite in space than on the ground. The main disadvantage is that there will be some degradation to the satellite's solar array due to its long-term bombardment by energy generated by solar flares and cosmic particles.

Using the reverse inclined orbit for operational purposes from day one has the advantage of halving the total amount of inclination achieved over a period of time. For example, a satellite launched into a reverse inclined orbit of ±0.8 degrees would reach geostationary operations at the end of one year and then increase again to an inclination of ±0.8 at the end of the second year. A satellite launched to geostationary orbit at the outset would achieve an approximate orbital inclination of 1.60 degrees over an equivalent period.

China Acquires SPACENET I

In 1992, GTE SPACENET and the China National Postal and Telecommunications Appliances Corporation (CNPTAC) signed a contract for the sale of GTE's Spacenet I satellite for use by the China Telecommunications Broadcast Satellite Company (ChinaSat). Spacenet I, previously located at 120 degrees West Longitude, will be flown to its new orbital assignment of 115.5 degrees East Longitude in the first half of 1993. The spacecraft will fill

in for the new 24-transponder Dong Fong Hong ("The East is Red") satellite, DFH-3 A1, scheduled for launch in late 1993 or early 1994.

China had expected to launch its own high capacity satellite, DFH3-A1, in 1992. However, the satellite was to be constructed using TWTAs and other technology from Western Europe. A trade embargo initiated by the United States prevented the components from being incorporated into the Chinese satellite, thereby delaying the program.

The satellite features twelve C-band transponders with 36 MHz bandwidths, six C-band transponders with 72 MHz bandwidths, and six Ku-band transponders with 72 MHz bandwidths. According to reports filed with the FCC, all of Spacenet I's transponders are in nominal operating conditions.

The geostationary lifetime of SPACENET I would have extended through 1996 if the satellite had maintained its location over the Americas. It has not been reported how much fuel will be used to relocate the satellite or how early the Chinese may initiate inclined orbit operations in order to extend the spacecraft's mission lifetime. We have included the satellite as part of this case study in the event that it moves toward an orbital inclination following its first couple of years of operation over the Asia/Pacific region.

1st contour:	36.2 dBW
2nd contour:	35.2 dBW
3rd contour:	34.2 dBW
4th contour:	31.2 dBW
5th contour:	28.2 dBW
6th contour:	25.2 dBW

FIG. 3-5. Spacenet I C-band beam coverage of China from 115.5 degrees East Longitude.

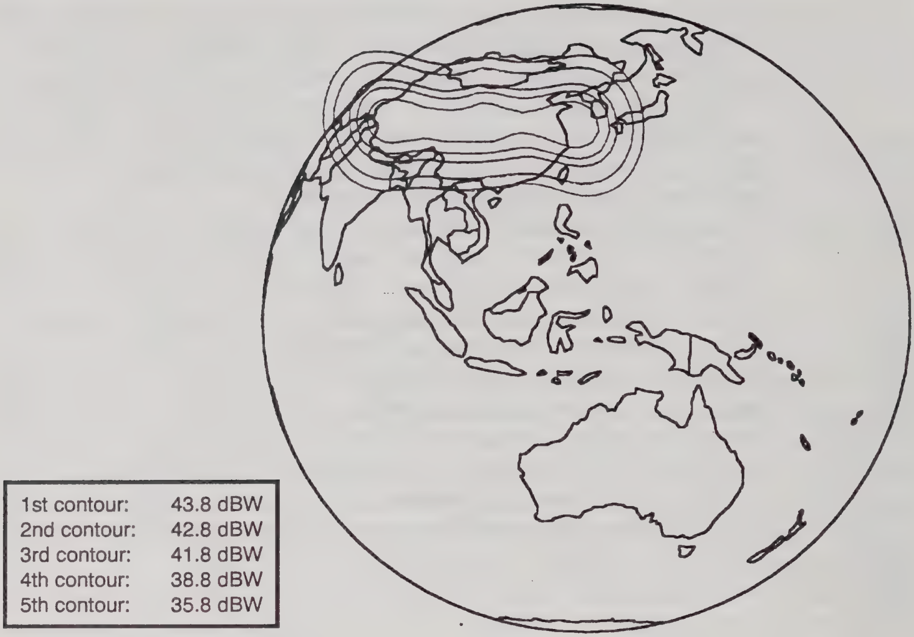


FIG. 3-6. Ku-band beam coverage of China from 115.5 degrees East Longitude.

The Spacenet I satellite became regarded as excess capacity for GTE SPACENET because of GTE's earlier aquisition of the ASC-1 and ASC-2 (currently known as Spacenet IV-n) satellites previously owned by Contel ASC. The hypothetical footprints presented above are based on patterns previously released by GTE SPACENET for American coverage and provide an indication of how the satellite would perform in its new Chinese role.

Comstar D4

The Chinese government also has purchased the aging Comstar D4 C-band satellite from the U.S. Comsat Corporation. Comstar D4, which was launched in 1981, provided AT&T with telecommunications services for seven years. More recently, the satellite has been operated in an inclined-orbit mode at 77 degrees West Longitude. At the time of writing, there had been no announcement as to the new orbital location for Comstar D4, nor any indication of just how the satellite will be used by the Chinese telecommunications authorities.

Inclined Orbit Operations Slated for Optus A2

On December 21, 1992, Australia's second generation Optus B2 satellite was launched from China via a Long March II rocket. However, after separation of the satellite from the launch vehicle, the Optus telemetry and tracking earth stations were unable to locate the spacecraft. During the early

moments of the launch a plume of smoke was observed coming out in the vicinity of the spacecraft fairing. According to Chinese launch officials, the fault must lay with the satellite and/or its apogee kick motor because the spacecraft separated from the launch vehicle at the correct moment. The loss of Optus B2 has forced Optus Communications into implementing an inclined orbit plan for for the existing Optus A2 satellite which is nearing the end of its conventional mission lifetime.

In the Fall of 1992, Optus put forward an inclined orbit plan for Optus A2 which drew the unmitigated ire of many of its satellite customers, who saw the plan as an Optus plot to maximize profits while providing minimum service. At that time, Optus sought to prolong the life of Optus B2 by placing it in a five-year storage orbit following launch. Continued use of the Optus A2 satellite would have been gained by maintaining the older satellite in an inclined orbit. Following a deluge of complaints, however, Optus subsequently withdrew the inclined orbit plan in favor of operating Optus B2 immediately. But now that Optus B2 has been lost, Optus has been forced to implement its inclined orbit plans for Optus A2 because it will be at least one and one-half years before Hughes can build and launch a replacement satellite.

Under the inclined orbit plan, Optus has relocated its A2 satellite to 164 degrees East Longitude and placed the spacecraft into an inclined orbit. The A3 satellite has been relocated to 156 degrees East Longitude, where it currently operates in a geostationary mode. Coverage of Australia's Optus Ku-band satellites is restricted to the continent of Australia and the nearby islands of Papua New Guinea, New Zealand, and Indonesia. Sites at fringe locations outside of the continent of Australia such as Papua New Guinea also are finding that their reception has suffered due to the shift in beam pointing as the satellite moves along the inclined orbit path.

TDRS-1

In 1993, NASA announced that it would be relocating its TDRS-1 satellite to 85 degrees East Longitude, where it will perform a scientific mission. The satellite, which was launched on April 4, 1983, carries a C-band telecommunications payload that potentially could be used for commercial telecommunications on a limited basis.

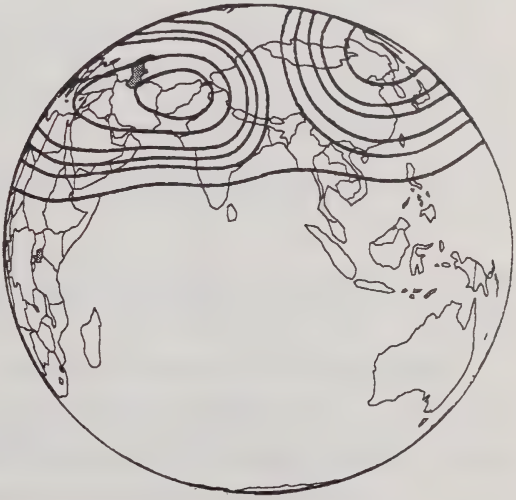


FIG 3-7. Possible C-band coverage for TDRS-1 from 85 degrees West.

Europe, Africa and the Middle East

As of early 1993, there were several inclined orbit satellites which could be received from locations throughout Europe, Africa and the Middle East. Moreover, additional satellites will become available in inclined orbits during the years ahead. Table 3-5 shows the orbital locations and inclinations for these satellites.

Table 3-5. Inclined orbit satellites viewable from Europe, Africa and the Middle East.

Satellite Name	Orbital Location	Estimated Degrees of Inclination (Beginning of Year) 1993	1994	1995	1996
STATSIONAR 21†	103° EAST	0.90°	1.75°	2.55°	3.35°
STATSIONAR 14†	96° EAST	1.42°	2.27°	3.07°	3.87°
INTELSAT 501	91.5° EAST	4.26°	5.11°	5.91°	6.81°
STATSIONAR 6†	90° EAST	0.39°	1.24°	2.04°	2.84°
STATSIONAR 3†	85° EAST	0.49°	1.34°	2.14°	2.94°
TDRS-1	85° EAST	6.74°	7.59°	TBR	TBR
STATSIONAR 13†	80° EAST	0.55°	1.35°	2.15°	2.95°
INTELSAT 505	66° EAST	2.79°	3.64°	4.44°	TBR
INTELSAT 507	57° EAST	2.38°	3.23°	4.03°	TBR
STATSIONAR 5	53° EAST	1.24°	2.09*	2.89*	2.69*
STATSIONAR 12*	40° EAST	0.57°	1.42*	2.22*	3.02*
ANIK D2	19° EAST	0.0°	TBD	TBD	TBD
INTELSAT 512	1° WEST	0.0°	0.85°	1.65°	TBR
STATSIONAR 11†	11° WEST	1.19°	2.04°	2.84°	3.64°
STATSIONAR 4†	14° WEST	0.68°	1.53°	2.33°	3.13°
INTELSAT 502	21.5° WEST	3.71°	4.56°	5.36°	6.16°
INTELSAT 504	31° WEST	3.34°	4.19°	4.99°	TBR
INTELSAT 506	50° WEST	1.78°	2.63°	3.43°	4.23°

† Russian satellites are replaced at frequent intervals and there is no guarantee that the present occupants of the Statsionar 21 (Gorizont 18), Statsionar 14 (Gorizont 19), Statsionar 6 (Gorizont 21), Statsionar 13 (Gorizont 24), Statsionar 5 (Gorizont), Statsionar 11 (Gorizont) and Statsionar 4 (Gorizont) orbital slots will remain at their current locations over the projected period. Any replacement satellites would begin operations at a lower value of inclination, increasing at a rate of approximately 0.80° per year.

* Recent reports indicate that the Russians may be contractually obligated to keep the Statsionar 12 satellite geostationary under the terms of its contract with France Telecom.

TBR = To be replaced by newer satellite with full stationkeeping

TBD = To be determined following inception of service in early 1993.

Inclined Orbit INTELSAT Satellites

Due to delays in the launch of the new generation INTELSAT VII series satellites, INTELSAT is operating several INTELSAT V satellites in inclined orbits in order to extend their orbital lifetimes and offer scarce international satellite capacity to its customers.

INTELSAT Southeast Asia Satellite. A new fourth region, in addition to the three regions currently served by INTELSAT, has been established to supply much needed capacity for customers in Southeast Asia. At the time of writing, INTELSAT 501 was drifting towards 91.5 degrees East Longitude from its previously assigned location over the Pacific Ocean. The satellite is expected to enter service at its new orbital position in the first quarter of 1993. No information concerning possible TV traffic has been released to date.

INTELSAT Indian Ocean Region Satellites. INTELSAT 505 at 66 degrees East Longitude is scheduled to be replaced by a new generation INTELSAT VII satellite by mid-1995. At the time of writing, the satellite's C-band capacity was providing TV transmissions for Worldnet on global beam transponder 38 [24] and ORTZ Zaire on West hemispheric transponder 12 [05].

INTELSAT 507, currently located at 57 degrees East Longitude, is scheduled to be replaced by INTELSAT 512 in 1995. The satellite transmits international news feeds on global beam transponder channels 38 [23] and 38 [24]. TV Ethiopia and TV Sudan also are reported to use West hemispheric beam transponders 13 [09] and 13 [11] to reach TV relay stations in Africa.

Atlantic Ocean Region INTELSAT Satellites. Located at 1 degree West (359 degrees East) Longitude, INTELSAT 512 is scheduled to be placed into an inclined orbit in early 1993. This satellite will be replaced by an INTELSAT VII series spacecraft by mid-1995. At the time of writing, B-MAC encrypted transmissions of AFRTS were carried by global beam transponder 38 [24] and Northeast zone beam transponder 53[10]. TV services of Gabon, Tele-Sahel Niger, TV Algerie, also were relayed by East hemispheric beams transponders. On Ku-band, the East spot beam provides three channels of Israeli TV and the West spot beam multiple channels of Norwegian TV.

Collocated at 21.5 degrees West (332.5 degrees East) Longitude with the Ku-band INTELSAT K satellite, INTELSAT 502 provides C-band services to Latin America via West hemispheric and global beams. At the time of writing, INTELSAT 502 carried a daily news feed from TV Globo New York to Rede Globo in Rio de Janeiro on global beam transponder 38 [23]. INTELSAT plans to continue to operate this satellite at 21.5 degrees West Longitude in an inclined orbit mode through the end of 1996.

Positioned at 31 degrees West (329 degrees East) Longitude, INTELSAT 504 was not beaming any TV traffic to the region at the time of writing. The satellite is scheduled to continue operations at 31 degrees West Longitude until the beginning of 1995.

Located at 50 degrees West (310 degrees East) Longitude, INTELSAT 506 is scheduled to provide continuing service through the end of 1996. At the time of writing, the satellite was transmitting no TV traffic into the region.

STATSIONAR Satellites

The Russian STATSIONAR satellites are almost always operated in an inclined orbit mode, even from the very beginning of service. Although we have projected future orbital inclinations for the present occupants of the STATSIONAR 11 and 4 satellites, keep in mind that Russian satellites are replaced at frequent intervals and there is no guarantee that the present occupants of these orbital slots will remain at their current locations over the projected period. Any future replacement satellites would begin operations at a lower value of inclination, increasing at a rate of approximately ±0.80 degrees per year.

STATSIONAR 21 (Gorizont 25—1993) at 103 degrees East Longitude carries one full-time TV service in SECAM from Moscow in spot beam transponder 6 [-1], TV Azerbaidjan on North hemispheric beam transponder 10[9]. Asia TV TWO (Sun TV), a Tamil-language service in PAL, also is expected to start operations in the near future on this satellite.

STATSIONAR 14 (Gorizont 19—1993) at 96.8 degrees East Longitude carries one full-time TV service in SECAM from Moscow in spot beam transponder 6 [-1], China's CCTV-4 in PAL on global beam transponder 9[6], and Asia TV Gold, a Hindi- and English-language service, in PAL on North hemispheric beam transponder 10[9].

STATSIONAR 6 (Gorizont 21—1993) at 90 degrees East Longitude carries three full-time TV services in SECAM from Moscow in spot beam transponder 6 [-1], North hemispheric beam transponder 10[9] and global beam transponder 11[11].

STATSIONAR 3 (Raduga 26—1993) at 85 degrees East Longitude carries a single TV service in PAL called "Ahmadiyya Muslim TV" which airs on Fridays and Saturdays.

STATSIONAR 13 (Gorizont 24—1993) at 80 degrees East Longitude carries one full-time TV service in SECAM from Moscow in spot beam transponder 6 [-1] and Intersputnik TV regional feeds on North hemispheric beam transponder 10[9].

STATSIONAR 5 (Gorizont 17—1993) at 53 degrees East Longitude carries two full-time TV services in SECAM from Moscow in spot beam transponder 6 [-1] and North hemispheric beam transponder 10[9].

STATSIONAR 12 (Gorizont 22—1993) at 40 degrees East Longitude carries one full-time TV service in SECAM from Moscow in spot beam transponder 6 [-1] TV5 France on global beam transponder 7[1] and Portugal's RTP International on North hemispheric beam transponder 10[9].

At the time of writing, STATSIONAR 11 (Gorizont 26—1993) carried one full-time TV service in SECAM from Moscow in global beam transponder 6 [-1] and occasional news feeds in PAL from the Moscow Bureau of the European Broadcasting Union (EBU) in global beam transponder 9[6].

STATSIONAR 4 (Gorizont 20—1993) relays programs from RFO France and Antenne 2 to Madagascar in SECAM and transmits TV Madagascar in SECAM through global beam transponder 7[1]. Global beam transponder

9[6] is used in the mornings (South American time) to transmit news feeds in SECAM for various Eastern European TV organizations and in the evenings to transmit several hours of Cuban TV in NTSC.

Arabsat Acquires Anik D2

In 1993, the Arabsat organization signed an agreement with Telesat Canada governing the sale of the Anik D2 C-band communications satellite. Anik D2 was initially designed to serve as part of Canada's domestic satellite system. Most recently, however, the satellite was used by GE Americom to replace the ailing Satcom F4R satellite in December of 1991. With the successful launch of its new generation Satcom C3 and C4 satellites, GE no longer required the use of Anik D2. Control of the spacecraft was returned to Telesat Canada on April 1, 1993. Telesat is now drifting the satellite to a new orbital assignment at 19 degrees East Longitude. Anik D2 is expected to arrive on station in late August of this year. Following a comprehensive technical check-out by Arabsat and Telesat, the satellite will be placed into operational service.

Because of low reserves of stationkeeping fuel, Anik D2 is being slowly drifted to its new orbital assignment to conserve precious fuel. Moreover, the satellite will be operated in an inclined orbit mode from day one at its new assigned position. Telesat expects that the satellite will remain functional through the end of 1995—long enough for Arabsat to launch the first of its new generation Arabsat II multiband (S/C/Ku-band) spacecraft.

FIG. 3-8. ANIK D2 Coverage from 19 degrees East Longitude

1st contour: 36 dBW
2nd contour: 33 dBW

Telesat's contract with Arabsat includes Telesat's supply of telemetry, telecommunications, and command (TT&C) services. While the TT&C facility will be physically based in Tunis, Telesat will maintain direct control through computer links to Telesat's control center in Toronto, Canada.

Arabsat was forced to take this interim measure because of the premature loss of fuel experienced by its Arabsat 1-A and 1-B satellites which occurred last year—even though the use of the Comsat Maneuver was supposed to extend the operational lifetimes of the two satellites for several additional years. Experts believe that the cause of the twin failures was due to fuel mismanagement by the Arabsat technical staff. By allowing Telesat Canada to maintain control of the spacecraft, Arabsat ensures that the satellite will be maintained by a knowledgable technical staff with plenty of experience in flying spin-stabilized spacecraft.

Anik D2 will provide supplemental capacity for Arabsat 1-C which, at the time of writing, was fully loaded with television and telephony traffic. Reports from the region indicate that Anik D2 will provide several transponders for the transmission of compressed digital video (CDV) services.

Once the satellite arrives at its new orbital location, expect Anik (Eskimo for "Little Brother") D2 to be renamed. During previous negotiations with Telesat, Arab representatives humorously told Telesat officials that in Arabic "Anik" is an obscene word.

A History of Anik D2. Anik D2 was built for Telesat by Spar Aerospace Ltd. of Toronto under an $80.8 million contract awarded in 1979. Hughes Aircraft also served as the largest subcontractor on the project.

On November 9, 1984, Anik D2 was launched into a unique, two-year storage orbit located at 111.5 degrees West Longitude. Telesat determined that even though the satellite was not immediately needed, it would be much less expensive to store the satellite in space than on Earth because of an anticipated increase in launch costs over the next two years.

Technical Specifications. Anik D2 is a standard 24-transponder C-band satellite based on the immensely successful Hughes HS-376 platform. Each transponder is capable of transmitting 960 one-way analog voice circuits or one conventional TV signal. Powered by 11.5 watt TWTAs, the satellite's single C-band beam will be tilted South to cover Northern Africa and the Middle East with a nominal EIRP of 36 dBW.

The spacecraft bus is a spin-stabilized structure with concentric, cylindrical solar panels that soak up energy from the Sun and provide close to 1,000 watts of electrical power under normal operations. Following relocation, however, Telesat is expected to retract the lower drum, thereby covering a portion of the satellite's solar array. While this will limit the number of available transponders to 22, additional station-keeping fuel savings will be realized because of the shift in the bird's center of gravity.

CHAPTER FOUR: COMMUNICATIONS SATELLITES IN GEOSYNCHRONOUS ORBIT

The following list was compiled by Jim Roberts of Gourmet...Entertaining from the *NASA Goddard Satellite Situation Report* of 9/30/92, the *NASA Synchronous Satellite Catalog* for 3/2/93 (Epochs through 93 61), and subsequent two-line elements (data report of satellite position and movement characteristics as of that point in time) drawn from the Goddard Space Center computer bulletin board. Annotations and updates of orbital assignments by Mark Long. All inclined orbit satellites are listed in bold print.

Table Terminology

Orbital Inclination: in degrees out of the Earth's Equatorial plane.

Eccentricity: the daily swing in degrees of East/West longitude due to orbital eccentricity due to the satellite's orbit being "out of round".

Epoch: the time, noted as the year and the day, of the orbital position and movement characteristics.

Satellite	Nation/ Org.	Launch Date	Orbital Location	Inclin-ation	Eccen	Epoch.
INTELSAT 503	**INTELSAT**	**12/15/81**	**177.0 W**	**3.55**	**.02**	**93 60**
TDRS 5	U.S.A.	8/2/91	174.4 W	0.02	.02	93 60
Raduga 21	**Russia**	**12/10/87**	**170.3 W**	**3.39**	**.02**	**93 60**
Loutch 3	**Russia**	**4/26/88**	**157.8 W**	**3.09**	**.15**	**93 57**
TDRS 6	U.S.A.	1/31/93	150.0 W	0.07	.01	93 58
	(moving to 62 W, replacing TDRS 3)					
Aurora 2/Satcom C5	U.S.A.	5/29/91	139.0 W	0.03	.01	93 59
Satcom C1	U.S.A.	11/20/90	137.1 W	0.05	.01	93 60
Satcom C4	U.S.A.	8/31/92	134.9 W	0.05	.01	93 57
Galaxy 1	U.S.A.	6/28/83	132.9 W	0.01	.01	93 57
Satcom C3	U.S.A.	9/10/92	130.8 W	0.06	.02	93 55
ASC 1	U.S.A.	8/27/85	127.9 W	0.02	.01	93 57
Galaxy 5	U.S.A.	3/14/92	125.1 W	0.01	0	93 60
GStar 2	U.S.A.	3/28/86	124.9 W	0.02	0	93 61
Telstar 303	U.S.A.	6/19/85	123.0 W	0.01	.01	93 61
SBS 5	U.S.A.	9/8/88	122.9 W	0.01	0	93 57
Morelos F2	Mexico	11/27/85	116.7 W	0.01	.01	93 58
Anik C3	**Canada**	**11/12/82**	**114.9 W**	**1.44**	**.01**	**93 59**
Morelos F1	Mexico	6/17/85	113.5 W	0.01	.01	93 58
Anik E1	Canada	9/26/91	111.0 W	0.05	.02	93 58
Anik E2	Canada	4/5/91	107.3 W	0.02	.01	93 60
GStar 4	U.S.A.	11/20/90	105.0 W	0.01	0	93 60
GStar 1	U.S.A.	5/8/85	103.0 W	0.01	0	93 61
Spacenet 4-n	U.S.A.	4/13/91	101.0 W	0.01	.01	93 59
SBS 6	U.S.A.	10/12/90	99.1 W	0.01	.01	93 59
Galaxy 6	U.S.A.	10/12/90	99.0 W	0.01	.01	93 59
SBS 2	**U.S.A.**	**9/24/81**	**97.0 W**	**4.56**	**.01**	**93 59**
Telstar 301	U.S.A.	7/28/83	96.0 W	0.02	.01	93 61

Satellite	Nation/ Org.	Launch Date	Orbital Location	Inclin- ation	Eccen	Epoch.
SBS 3	**U.S.A.**	**11/11/82**	**95.0 W**	**1.36**	**.01**	**93 59**
Galaxy 3	U.S.A.	9/21/84	93.5 W	0.03	.01	93 60
GStar 3	**U.S.A.**	**9/8/88**	**93.0 W**	**4.78**	**.01**	**93 60**
Galaxy 7	U.S.A.	10/27/92	91.1 W	0.04	.01	93 55
Spacenet 3	U.S.A.	3/11/84	87.0 W	0.05	.01	93 59
Telstar 302	U.S.A.	9/1/84	85.1 W	0.03	0	93 58
Satcom K1	U.S.A.	1/12/86	85.0 W	0.01	.01	93 61
Anik C2	**Argentina**	**6/18/83**	**(Moving to 76.2 W/Begin - 8/93)**			
Anik C1	Argentina	4/13/85	(Moving to 71.8 W/Begin-6/93)			
Satcom K2	U.S.A.	11/28/85	81.0 W	0.03	.01	93 61
SBS 4	**U.S.A.**	**8/31/84**	**77.0 W**			
	(moving to new location/to start in inclined orbit mode.)					
Galaxy 2	U.S.A.	9/22/83	74.1 W	0.02	.01	93 58
Satcom F2R	U.S.A.	9/8/83	72.0 W	0.06	.02	93 58
Brazilsat A2	Brazil	3/28/86	70.0 W	0.04	0	93 58
Spacenet 2	U.S.A.	11/10/84	69.0 W	0.05	.01	93 59
Brazilsat A1	Brazil	2/8/85	65.0 W	0.01	0	93 58
TDRS 3	U.S.A.	9/29/88	62.1 W	0.05	.01	93 59
	(moving to 171 W/to be replaced by TDRS 6)					
Inmarsat II F4	**Inmarsat**	**4/15/92**	**54.0 W**	**2.22**	**.02**	**93 58**
INTELSAT 513	INTELSAT	5/17/88	53.0 W	0.07	.01	93 67
INTELSAT 506	**INTELSAT**	**5/19/83**	**50.0 W**	**2.01**	**.02**	**93 69**
PAS-1	PanAmSat	6/15/88	45.0 W	0.03	.01	93 68
TDRS 4	U.S.A.	3/13/89	41.0 W	0.05	0	93 60
INTELSAT 603	INTELSAT	3/14/90	34.5 W	0.01	0	93 66
INTELSAT 504	**INTELSAT**	**3/5/82**	**31.5 W**	**3.56**	**.02**	**93 60**
Marcopolo 1	U.K.	9/27/89	31.0 W	0.01	.01	93 58
Hispasat 1A	Spain	9/10/92	30.1 W	0.03	0	93 56
INTELSAT 601	INTELSAT	10/29/91	27.7 W	0.02	.01	93 54
Raduga 23	**Russia**	**4/14/89**	**25.1 W**	**2.03**	**.01**	**93 59**
INTELSAT 605	INTELSAT	8/14/91	24.5 W	0.04	0	93 58
INTELSAT K	INTELSAT	6/10/92	21.5 W	0.02	.01	93 61
INTELSAT 502	**INTELSAT**	**12/6/80**	**21.3 W**	**3.92**	**.03**	**93 58**
TV-Sat 2	Germany	8/8/89	19.2 W	0.04	.04	93 59
Olympus	**ESA**	**7/12/89**	**19.0 W**	**0.82**	**.03**	**93 59**
TDF-1	France	10/28/88	18.8 W	0.09	.01	93 59
TDF-2	France	7/24/90	18.8 W	0.08	.02	93 59
INTELSAT 515	INTELSAT	1/27/89	18.0 W	0.08	.02	93 58
Loutch 2	**Russia**	**12/27/89**	**15.9 W**	**1.33**	**.01**	**93 60**
Inmarsat II F2	**Inmarsat**	**3/8/91**	**15.5 W**	**2.19**	**.02**	**93 60**
Gorizont 20	**Russia**	**6/20/90**	**14.4 W**	**0.88**	**.03**	**93 59**
Geizer/Potok 1	**Russia**	**11/22/91**	**14.1 W**	**0.34**	**.02**	**93 60**
Gorizont 26	**Russia**	**7/14/92**	**11.0 W**	**1.99**	**.03**	**93 59**
Telecom II F1	France	12/16/91	8.0 W	0.01	.01	93 61
Telecom II F2	France	4/15/92	5.0 W	0.04	.02	93 61
INTELSAT 512	INTELSAT	9/29/85	1.0 W	0.04	.03	93 59
Thor	Norway	8/18/90	0.8 W	0.01	.03	93 58
EUTELSAT I F2	**EUTELSAT**	**8/4/84**	**1.0 E**	**2.28**	**.02**	**93 58**
Telecom I F3	France	3/11/88	3.0 E	0.04	.01	93 58
Tele-X	Sweden	4/2/89	5.0 E	0.02	.02	93 57

Satellite	Nation/ Org.	Launch Date	Orbital Location	Inclin- ation	Eccen	Epoch.
EUTELSAT II F4	EUTELSAT	7/9/92	7.0 E	0.02	.03	93 57
EUTELSAT II F2	EUTELSAT	1/15/91	10.0 E	0.02	.02	93 56
EUTELSAT II F1	EUTELSAT	8/30/90	13.0 E	0.03	.03	93 58
Italsat 1	Italy	1/15/91	13.1 E	0.01	.09	93 57
EUTELSAT II F3	EUTELSAT	12/7/91	16.0 E	0.02	.01	93 58
Anik D2	**Arabsat**	**11/9/84**	**19.0 E (To Begin 9/93 inclined)**			
Astra 1B	Luxembourg	3/2/91	19.2 E	0	.03	93 58
Astra 1A	Luxembourg	12/11/88	19.3 E	0.02	.02	93 58
EUTELSAT I F5	EUTELSAT	7/21/88	21.6 E	0.04	.03	93 58
DFS Kopernikus 3	Germany	10/12/92	23.5 E	0.02	.01	93 58
EUTELSAT I F4	EUTELSAT	9/16/87	25.7 E	0.03	.06	93 45
EUTELSAT I F1	**EUTELSAT**	**6/16/83**	**25.7 E**	**3.17**	**.01**	**93 59**
DFS Kopernikus 2	Germany	7/24/90	28.6 E	0.02	.01	93 60
Arabsat 1C	Arabsat	2/26/92	31.2 E	0.03	.08	93 58
Raduga 19	**Russia**	**10/25/86**	**34.4 E**	**4.48**	**.01**	**93 60**
DFS Kopernikus 1	Germany	6/5/89	37.3 E	0.03	.04	93 54
Gorizont 22	**Russia**	**11/23/90**	**39.9 E**	**0.57**	**.01**	**93 60**
Raduga 1-2	**Russia**	**12/27/90**	**48.9 E**	**0.45**	**.01**	**93 60**
Gorizont 27	**Russia**	**?**	**52.8 E**	**1.24**	**0**	**93 60**
INTELSAT 507	**INTELSAT**	**10/19/83**	**57.0 E**	**2.36**	**.28**	**93 59**
INTELSAT 604	INTELSAT	6/23/90	60.0 E	0.03	.01	93 59
INTELSAT 602	INTELSAT	10/27/89	63.0 E	0.02	.08	93 60
Inmarsat II F1	**Inmarsat**	**10/30/90**	**64.4 E**	**1.76**	**.10**	**93 59**
INTELSAT 505	**INTELSAT**	**9/28/82**	**66.0 E**	**3.00**	**.03**	**93 60**
Raduga 25	**Russia**	**2/15/90**	**70.4 E**	**1.21**	**.01**	**93 60**
Insat 2A	India	7/9/92	74.0 E	0.06	.03	93 42
Geizer/Potok 2	**Russia**	**7/18/90**	**79.8 E**	**0.83**	**.01**	**93 60**
Gorizont 24	Russia	10/23/91	80.3 E	0.35	.01	93 60
Insat 1D	India	6/12/90	83.1 E	0.06	.05	93 59
Raduga 26	**Russia**	**12/20/90**	**84.7 E**	**0.49**	**0**	**93 60**
TDRS 1	**U.S.A.**	**4/4/83**	**85.0 E**	**6.74**		
	(Moving to this new location in 1993)					
Chinasat 1	China	3/7/88	87.5 E	0.05	.01	93 60
INTELSAT 501	**INTELSAT**	**5/23/81**	**91.5 E**	**4.47**	**.05**	**93 59**
Gorizont 21	**Russia**	**11/3/90**	**89.7 E**	**0.62**	**.01**	**93 60**
Gorizont 19	**Russia**	**9/28/89**	**96.8 E**	**1.64**	**.01**	**93 60**
Loutch 1	Russia	9/13/91	97.8 E	0.07	.03	93 59
Ekran 19	**Russia**	**12/8/88**	**99.3 E**	**2.37**	**.05**	**93 59**
Gorizont 25	**Russia**	**4/2/92**	**103.1 E**	**0.68**	**.02**	**93 60**
Asiasat 1	Hong Kong	4/7/90	105.4 E	0.03	0	93 58
Palapa B2R	Indonesia	4/13/90	107.9 E	0.01	0	93 57
BS-3B	Japan	8/25/91	109.9 E	0.05	.02	93 60
BS-3A	Japan	8/28/90	110.0 E	0.04	.02	93 58
Chinasat 2	China	12/22/88	110.7 E	0.05	0	93 60
Palapa B2P	Indonesia	3/21/87	113.0 E	0.02	0	93 60
Spacenet I	China	5/23/84	115.5 E			
	(To Begin operatons 4/15/93 in geostationary mode)					
Comstar D4	**China**	**2/21/81**	**?**	**6.51**	**0**	**93 58**
	(Moving to a new orbital location for China)					
Palapa B4	Indonesia	5/14/92	117.9 E	0.04	.02	93 48
Raduga 27	**Russia**	**2/28/91**	**128.6 E**	**0.55**	**.01**	**93 60**

Satellite	Nation/ Org.	Launch Date	Orbital Location	Inclin- ation	Eccen	Epoch.
CS-3A	Japan	2/19/88	132.0 E	0.05	0	93 59
Palapa Pacific/B1	**Indonesia**	**6/18/83**	**133.9 E**	**2.54**	**0**	**93 58**
Rimsat 1/Raduga?	**Tonga**	**?**	**134.0 E**			
	(To begin operations 6/93 in inclined orbit mode)					
CS-3B	Japan	9/16/88	136.0 E	0.04	0	93 61
Gorizont 18	**Russia**	**7/5/89**	**140.2 E**	**1.74**	**.01**	**93 59**
JCSat 1	Japan	3/6/89	150.0 E	0.02	.01	93 61
ETS-V	**Japan**	**8/27/87**	**150.3 E**	**1.50**	**.03**	**93 61**
JCSat 2	Japan	1/1/90	153.9 E	0.01	.01	93 59
Optus A2	**Australia**	**11/27/85**	**156.0 E**	**0.01**	**.01**	**93 61**
	(since moved to 164 E, operating in inclined orbit mode)					
Superbird A1	Japan	12/1/92	158.0 E	0.02	.02	93 60
Optus B1	Australia	8/13/92	160.0 E			
Superbird B2	Japan	2/26/92	162.0 E	0.02	.03	93 60
Optus A3	Australia	9/16/87	164.0 E	0.02	.01	93 59
	(since moved to 156 E, still operating in geostationary mode)					
INTELSAT 510	**INTELSAT**	**3/22/85**	**174.0 E**	**0.61**	**.03**	**93 61**
INTELSAT 511	**INTELSAT**	**6/30/85**	**177.0 E**	**0.18**	**.03**	**93 61**
Inmarsat II F3	**Inmarsat**	**12/16/91**	**178.0 E**	**1.85**	**.01**	**93 60**
INTELSAT 508	**INTELSAT**	**5/5/84**	**180 E**	**1.68**	**.02**	**93 60**

(About one-third of all active—or soon to be active—commercial communications satellites are inclined more than ±0.1 degrees. If one factors in the active weather, military, landsat, spy, etc. satellites, then the number of inclined orbit satellites exceeds 40 percent!)

A Glossary of Satellite Related Terminology

A

Analog—A signal waveform that can be continuously variable in intensity and/or frequency. (Also see digital).

Anik C1 & C2—Ku-band communications satellites transferred to Argentina's PARACOM S.A. in 1993 by owner Telesat Canada for use as part of Argentina's Nahuel domestic satellite system.

Antenna Control Units (ACUs)—Microprocessor-based terminals which are used to controls the movements of a satellite antenna.

Antenne-2—France's second terrestrial TV channel.

AOR—Atlantic Ocean Region (as defined by INTELSAT).

Aperture—The effective diameter of a parabolic antenna which intercepts the incoming microwave signal.

ARABSAT—Arab Satellite Communications Organization with one satellite operating from 31 degrees East Longitude.

Attenuation—The measure of signal loss in a transmission medium or component usually expressed in deciBels (dBs) or deciBels per unit length (kilometer or mile). Satellite transmissions at the higher end of the microwave frequency bands are more susceptible to attenuation caused by heavy rains.

Attitude—The orientation of a communications satellite in relation to the Earth's polar axis.

AZ—the azimuth angle (see azimuth).

Azimuth—Angle between the receiving antenna and the longitudinal location of the satellite sub-point over the Earth's equator.

B

Band—A unit for designating a specific frequency or range of frequencies in the electromagnetic spectrum.

Bandwidth—The range of frequencies occupied by a signal, or passed by a transmission channel. Services requiring a bandwidth greater than 20 kHz, such as TV transmissions, are known as "broadband." Those requiring less capacity, such as audio transmissions, are known as "narrowband."

BDC—Block Downconverter or Block Downconversion.

Beam pattern—The unique coverage area created by any communications satellite's transmitting (or receiving) parabolic antenna.

Block Downconversion—The use of a fixed-frequency first local oscillator, to downconvert an entire satellite band to a lower intermediate frequency for subsequent tuning and demodulation.

B-MAC—see MAC.

Boresight—Axis of symmetry of a parabolic antenna. (In layman's terms: the beam center).

C

Carrier—The radio frequency wave that is

modulated by the baseband information signal.

Cassegrain—Dual-reflector antenna geometry using a convex hyperboloidal subreflector and paraboloid main reflector.

CATV—Community Antenna (Cable) Television.

C-band—Used loosely for satellite downlinks within the 3.4 to 4.2 GHz frequency range.

Channel—a one-way communications link. The connections for satellite TV transmissions are called channels. The volume of satellite television usage is measured in hours per channel.

Clarke Orbit—see GEO.

CNR or C/N—Carrier-to-Noise Ratio

Collocation—Ability of multiple satellites to share the same approximate geostationary orbital assignment.

COMSAT—Communications Satellite Corporation. U.S. corporation providing operational and technical services to INTELSAT, and operating its own domestic satellite systems.

Comsat Maneuver—A proprientary technique developed by COMSAT to control the beam pointing of a inclined orbit satellite so that the beam pattern remains continuously fixed over the desired coverage area.
CONUS—contiguous United States.
CP—Circular Polarization.

D

dB—deciBel. A means of expressing ratios logarithmically. Number of dB = 10 x log(base 10) of power ratio. So, 3 dB represents a factor of 2, 10 dB a factor of 10, 20 dB a factor of 100, etc.

dBi—dB antenna gain relative to an isotropic source.

DBS—Direct Broadcasting (by) Satellite.

dBW—dB power relative to one watt.

Declination—The offset angle of an antenna from its polar mount axis.

Diurnal—The orbital movement of a satellite where the spacecraft crosses the Earth's equator twice during each 24-hour period.

Domsat—Domestic Communications Satellite.

Doppler Effect—A frequency shift which occurs due to the signal delays which take place as an inclined orbit satellite moves closer or further away from the receiving site.

Downconversion—Translation of frequency or a block of frequencies to a lower portion of the electromagnetic spectrum.

Downlink—The space-to-Earth half of a two-way telecommunications satellite link. (Also see Uplink).

Dual-Axis Tracking—An antenna positioning system which requires two independent movements in Azimuth and Elevation in order to locate any communications satellite.

D2-MAC—see MAC.

E

EBU (also UER)—European Broadcasting

Union.

Eclipse—Period when the satellite passes into the Earth's (or the Moon's) shadow, when power must be drawn from storage batteries.

Eclipse-protected—Refers to a transponder that can remain powered during the period of an eclipse.

Edge of Coverage—Limit of defined service area, typically 3 dB down from beam center, but may be more. Reception is still possible beyond this line. (Also see Spillover.)

EIRP (or e.i.r.p.)—Equivalent Isotropically Radiated Power (or Effective Isotropic Radiated Power). Combined result of transmitter (or transponder) RF power, and transmitting antenna gain.

El/Az (El over Az)—An antenna mount providing independent steering in Azimuth and Elevation.

Electromagnetic Spectrum—The entire range of wavelengths of electromagnetic radiation—including visible light—which extend from gamma rays to microwaves and radio waves, all of which travel at the speed of light (186,000 miles per second or 300,000,000 meters per second).

Elevation—Angle between antenna beam and the horizon.

EUTELSAT—European Telecommunications Satellite Organization.

F

f/D—Focal-length-to-Diameter ratio (of an antenna's reflector).

Faraday Rotation—When peak sunspot activity highly charges the Earth's ionosphere, the vectors of linearly-polarized satellite signals can be rotated or "twisted" through interaction with the Earth's atmosphere.

Feed, Feedhorn—The small, widebeam antenna that illuminates (gathers signal from) the reflector in an antenna system (convention speaks of illumination, even in a receive- only application, as if the antenna were transmitting).

Footprint—Coverage area of a satellite beam; a contour map showing EIRP or antenna sizes within a satellite's coverage zone.

Frequency—The number of times that an alternating current goes through its complete cycle in one second of time. One cycle per second is also referred to as a Hertz, 1,000 cycles per second a kiloHertz, 1,000,000 cycles per second a megaHertz, and 1,000,000,000 cycles per second a gigaHertz.

Frequency reuse—A technique which maximizes the capacity of a telecommunications satellite through the use of spatially-isolated beam antennas and/or the use of dual polarities.

FSS—Fixed-Satellite Service (see also BSS).

G

G—Giga-, one (US) billion or 10^9

GEO—The Geosynchronous Equatorial (Clarke) Orbit. Unique orbit in which a body can remain essentially stationary relative to Earth coordinates.

Geosynchronous—Prograde orbit having a period equal to that of Earth's rotation (need not imply geostationary).

Geostationary—see GEO.

GHz—Unit of frequency equal to 1000 MHz, one billion (109) cycles per second.

Global Beam—Beam covering the entire visible Earth surface, (42 percent of the globe) as seen from the satellite.

GMT—Greenwich Mean Time. The international universal standard time. See also UT.

Gorizont ("Horizon")—Russian FSS satellites serving the STATSIONAR system in the C- and Ku-bands.

G/T (G over T)—Gain-to-noise-Temperature ratio of a receiving system; its sensitivity or "figure of merit".

Guard Band—An unused spectra of frequencies which lie above and below each transponder. The guard band helps to prevent adjacent communications signals from interfering with one another.

H

Head Unit—Alternative term for an LNA, LNB, or LNC. Also called the outdoor unit.

Hemispheric Beam—Shaped beam covering approximately half of the visible Earth's surface (21 percent of the total globe), as seen from the satellite. INTELSAT spacecraft carry east and west hemispheric beams, while Russian Gorizont and Raduga satellites are equipped with northern hemispheric beams illuminating the visible portion of the globe which lies north of the equator.

Hertz—A unit of frequency. One cycle per second. (Also see frequency.)

Hz—Hertz—A unit of frequency. One cycle per second.

I

IF (or i.f.)—Intermediate Frequency (in a receiver).

Inclination—Angle between orbital plane of satellite and equatorial plane of the Earth.

INTELSAT—International Telecommunications Satellite Organization (and its satellites). The global telecommunications satellite system. INTELSAT's membership totaled 121 nations in 1992.

IOR—Indian Ocean Region (as defined by INTELSAT).

Isotropic—The property possessed by a hypothetical omnidirectional point-source antenna, the reference for antenna gain measurements.

K

k—Kilo-, one thousand or 10^3

K—see Kelvin.

K-band—The frequency spectrum 10.9 to 36 GHz.

Kelvin, K—Unit of absolute temperature, used in noise measurement. 273 Kelvin equals zero Celsius. Also degrees Kelvin, degrees absolute.

Ku-band—Used by satellite systems employing frequencies between 10.7 and 18 GHz.

L

Latitude—The distance, expressed in degrees, from the Earth's equator to points north or south. The equator is assigned a value of 0 degrees; North and South poles

are 90 degrees.

L-band—Used loosely to describe satellite systems downlinking in the region of 1.6 GHz.

LHCP (or LCP)—Left-Hand Circular Polarization.

LNA—Low-Noise Amplifier.

LNB (or LNBC)—Low-Noise Block (downconverter).

LNF—A combination of a feed, automatic polarizer and low noise amplifier in a common package.

Longitude—The distance in degrees from one meridian to any other is defined in terms of degrees of longitude. (Also see meridian and latitude).

Look Angle—The angle between the horizon and the amount an earth station antenna is tilted up to receive signals from, or send signals to, a satellite.

LOS—Line of Sight.

Low Power Satellite—Satellite with transponder RF power below about 30 watts.

M

m—Milli-, one-thousandth or 10^{-3}.

M—Mega-, one million or 10^{6}.

MAC (A-, B-, C- or D-)—Multiplexed Analog Components. An enhanced color TV transmission system developed especially for satellite use. Differences between the various types of MAC have to do with the various types of sound and data channels used.

Marginal—Describes a system operating with nil, or inadequate, signal margin.

MATV—Master Antenna Television—private cable. (Also see SMATV).

MBA—Multiple Beam Antenna.

Medium Power Satellite—Satellite with transponder RF power in the region of 30 to 60 watts.

Meridians—Lines circling from pole to pole which cross each of the 360 degrees which comprise the Earth's equator.

Modified Polar Mount—A satellite antenna mount, the design of which has been created to track the geostationary satellite arc by means of a single antenna movement called the actuation. This design, which is based on the True Polar Mounts used by astronomers' telescopes, has two modified adjustments which correct for the closer distances of satellites versus celestial objects and the latitude for each receiving site.

N

NASA—National Aeronautics and Space Administration. U.S. agency which administers the American space program, including the deployment of military satellites via its fleet of space transportation system (STS) space shuttles.

Noise Figure—Measurement of noise contribution of an amplifier relative to a noise-free amplifier at a reference temperature. Usually expressed in dB for Ku-band amplifiers.

Noise Temperature—Noise measurement of a system, as the absolute temperature of a resistive source delivering equal noise power. Expressed in (degrees) Kelvin for C-

band amplifiers.

O

Offset-fed Antenna—An antenna whose reflector forms only part of a paraboloid of revolution, usually excluding the pole or apex, such that a front feed causes no aperture blockage.

Orbit—The path along which a communications satellite moves in relationship to the Earth's surface. This path can either be parallel to the Earth's polar axis (polar orbit), parallell to the Earth's equator (equatorial) or inclined.

Orthogonal—Mutually at right angles (e.g., horizontal and vertical polarization, or right- and left-hand circular polarization).

P

Palapa—Indonesia/ASEAN regional satellite system.

Paraboloid—A parabola of revolution. Classical shape of a satellite antenna's reflector.

Planar Array—Flat satellite antenna composed of a gridwork of tiny resonant elements.

Pointing Error—The amount of difference between the direction in which the antenna is pointing—the beam focus or "boresight" of the antenna's main beam—and the actual direction of the satellite.

Polar Mount—Antenna mechanism permitting steering along the geostationary arc (Clarke Orbit) by rotation about a single axis. Also Equatorial Mount. A classical polar mount has its axis parallel to that of the Earth. Satellite receiving antennas use modified polar mount geometry, incorporating a declination offset.

Polarization—The property by which an electromagnetic wave exhibits a direction (or rotation sense) of vibration, giving the opportunity for frequency re-use by orthogonal polarizations.

Polarizer (also De-Polarizer)—A bi-refringent component in a waveguide or antenna system, which converts between linear (plane) and circular polarizations. Not a polarization rotor.

POR—Pacific Ocean Region (as defined by INTELSAT).

Prime Focus—The focal point of a paraboloid reflector. A feed system placed at that point.

R

Raduga ("Rainbow")—Russian FSS satellite serving the STATSIONAR system in the C-band frequency range.

Rain Outage—Loss of signal (esp. at Ku-band) due to absorption and thermal noise accompanying heavy rainfall.

RARC—Regional Administrative Radio Conference. See WARC.

Reverse Inclined Orbit—(See Storage Orbit.)

RF—Radio Frequency.

RHCP (or RCP)—Right-Hand Circular Polarization.

Rimsat—A U.S. based company which intends to operate several Russian satellites on behalf of customers wihtin the Pacific Ocean Region.

S

S-band—Satellite downlinks in the region of 2.6 GHz.

SBS—Satellite Business Systems (Satellites now owned by Hughes Communications).

Scalar Feed—The wide flare corrugated horn antenna feed, now standard in C-band home satellite TV receiving systems.

Sidelobe—Off-axis response of an antenna.

Sidereal Time—The period of the North-South motion of an inclined orbit satellite which is equivalent to 23 hours, 56 minutes, and 4 seconds in mean solar time.

Single Axis Tracking—An antenna positioning system which requires one independent movement in either Declination or Elevation in order to maintain its acquisition of an inclined orbit satellite.

Skew—The difference (real or apparent) in linear polarization angle between two (or more) different satellites, as modified by mount geometry.

SMATV—Satellite Master Antenna Television (see MATV).

S/N—See S/NR.

S/NR—Signal-to-Noise Ratio. A measure of how clean (noise-free) the recovered baseband signal is.

Solar Array—A network of solar cells which generate electricity when exposed to sunlight.

Solar Eclipse—When the Earth shadows the satellite's solar array from the Sun.

Solar Outage—Loss of signal caused by the sun passing through the receiving antenna's beam.

Sparklies—Popular term for impulse noise spikes visible as black or white spots or streaks in the TV picture, at CNR values close to threshold.

Spherical—Simple geometry for feed-steerable or multiple beam antenna.

Spillover—Usable (but often unwanted) signal reaching locations beyond defined Edge of Coverage.

Spot Beam—Beam of circular or elliptical cross-section, covering a defined region of the Earth's surface, small in relation to a global beam.

STATSIONAR—Russian geostationary communications satellite systems.

Storage Orbit—A predetermined orbit initiated during the launch phase. This orbit is calculated to take advantage of all natural forces impinging on the satellite—including solar winds and the effects of the gravitational fields of the Earth and Moon—so that as time goes on the inclination lessens without requiring any expenditure of stationkeeping fuel. At some predetermined time, the amount of inclination will reach zero degrees or actual geostationary operation.

Subcarrier—An information-carrying wave, which in turn modulates the main carrier in a communications system. Subcarriers are used for color information, TV audio, independent audio, and data transmission.

Subsatellite Point—The longitudinal point over the Earth's equator to which a commu-

nications satellite has been assigned by the International Frequency Registration Board of the ITU.

T

Telesat—Canada's domestic satellite organization, operating the Anik system.

Threshold—In an FM system, the value of CNR at which the linear relationship between CNR and demodulated signal SNR breaks down. (Also see Sparklies).

Threshold Extension—Techniques for reducing the CNR value at which threshold effects occur.

Transponder—The equipment forming a single repeater channel on board a satellite.

U

UHF—The spectrum 300 MHz thru 3 GHz. Terrestrial broadcast television occupies 470~890 MHz. The 620~790 MHz band is allocated for community DBS downlinks in developing countries and remote areas.

Uplink—The space-to-Earth telecommunications pathway.

UT—Universal Time. Same as GMT.

W

WARC—World Administrative Radio Conference. The ITU meetings that work out standards for international radio communications (including satellite TV).

Y

Yagi—A communications antenna consisting of a main metal boom that supports numerous quarter-wave elements. Used for reception of S-band TV signals from Arabsat.

Z

Zone beam—Beam pattern, usually a shaped beam, intermediate between hemispheric and spot.

Index

U

V

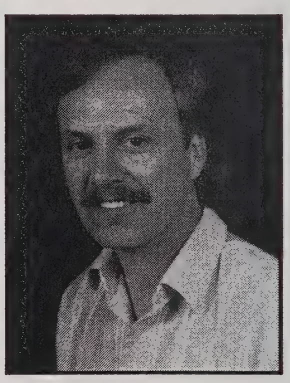
W

About the Authors

Mark Long is the world's leading journalist in the field of satellite communications. During the past ten years he has written more than 300 articles for magazines such as *Satellite Orbit, Satellite Direct, Orbit Video, TVRO Dealer, Satellite TV Week, Cable and Satellite Europe, Popular Communications, and Tele-satellit.* Dozens of his articles also have appeared in the newspapers of the *Los Angeles Times Syndicate.* Mr. Long also is the author of several books on satellite communications, including the best-selling **World of Satellite TV, The Down To Earth Guide to Satellite TV, The Ku-band Satellite Handbook,** and the critically-acclaimed **World Satellite Almanac**. More than 400,000 copies of his satellite-related books have been printed.

As president of MLE INC, Mark Long supervises the publication of a variety of periodicals, including the monthly newsletter *World Satellite Update,* the quarterly *World Satellite Transponder Report*, and the yearly *World Satellite Annual*. A long-time radio amateur radio operator (WA4LXC), Mr. Long also is a member of the *American Institute of Aeronautics and Astronautics* and the *International Society of Satellite Professionals.*

Jeffrey Keating is the co-author of the million-selling **Big Dummy's Guide to CB Radio** and the best-selling **World of Satellite TV**. A consultant in the field of international satellite communications, Mr. Keating has provided numerous companies with advice on the transmission and reception of video, voice, and data via satellite.



Over the years, Jeffrey Keating has been an FM broadcast station manager, an amateur radio (WB4KDH) net control operator for major relief efforts in Central America, and a pioneer member of the U.S. satellite TV industry. He presently is involved in the establishment of a non-profit satellite TV network for environmentalists and humanitarians.

Orbit	Inc.	Satellite Name	Operator/Country	Date	Bands	Pol.
53 W	±0.1°	INTELSAT 513	INTELSAT	1988	C1/K1-4	CP/LP
50 W	±2.01°	INTELSAT 506	INTELSAT	1983	C1/K3	CP/LP
47.5 W	—	OrionSat 2	Orion [U.S.]	1995	K	LP
45.5 W	±0.1°	PAS-1	PanAmSat [U.S.]	1988	C1/K1	LP
43 W	—	PAS-2	PanAmSat [U.S.]	1994	C1/K1	LP
37.5 W	—	OrionSat 1	Orion [U.S.]	1994	K	LP
34.5 W	±0.1°	INTELSAT 603	INTELSAT	1992	C2/K	CP/LP
31.5 W	±3.56°	INTELSAT 504	INTELSAT	1982	C1/K3	CP
30 W	±0.1°	Hispasat 1 & 2	Spain	1992/93	K3,4,6	CP/LP
27.5 W	±0.1°	INTELSAT 601	INTELSAT	1992	C2/K	CP/LP
24.5 W	±0.1°	INTELSAT 605	INTELSAT	1991	C2/K	CP/LP
21.5 W	±0.1°	INTELSAT K	INTELSAT	1992	K1-3	LP
21.3 W	±3.92°	INTELSAT 502	INTELSAT	1980	C1/K3	CP/LP
19 W	±0.1°	TDF-1 & TDF 2	France	1988/90	K6	CP
19 W	±0.1°	TV-Sat	Germany	1990	K6	CP
19 W	±0.82°	Olympus	European Space Agency	1989	K5/K6/Ka	CP/LP
18 W	±0.1°	INTELSAT 515	INTELSAT	1989	C1/K3-4	CP/LP
16 W	±1.33°	Loutch 2	CIS	1989	K5	RH
14 W	±0.88°	Stat. 4/Gorizont 20	CIS Intersputnik	1990	C3/K5	RH
11 W	±1.99°	Stat. 11/Gorizont 26	CIS	1992	C3/K5	RH
8 W	±0.1°	Telecom II-A	France	1991	C1/K4	LH/LP
5 W	±0.1°	Telecom II-B	France	1992	C1/K4	LH/LP
1 W	±0.1°	INTELSAT 512	INTELSAT	1985	C1/K3	CP/LP
0.8 W	±0.1°	Thor	Norwegian Telekom	1989	K6	CP
1 E	±2.28°	Eutelsat I F2	Eutelsat	1984	K3/K4	LP
3 E	±0.1°	Telecom I-C	France	1988	C1/K4	LH/LP
5 E	±0.1°	Tele-X	Swedish Space Corp.	1989	K4/K6	CP/LP
7 E	±0.1°	Eutelsat II F4	Eutelsat	1992	K3/K4	LP
10 E	±0.1°	Eutelsat II F2	Eutelsat	1991	K3/K4	LP
13 E	±0.1°	Eutelsat II F1	Eutelsat	1990	K3/K4	LP
15 E	—	Amos 1 & 2	Israel	1995	C1/K3	LP
16 E	±0.1°	Eutelsat II F3	Eutelsat	1992	K3/K4	LP
19 E	—	Arabsat II	Arab Sat. Org.	1994	C1/K/S	CP/LP
19.2 E	±0.1°	Astra 1A & 1B	SES Luxembourg	1988/91	K3	LP
19.2 E	—	Astra 1C & 1D	SES Luxembourg	1993/94	K3	LP
21.6 E	±0.1°	Eutelsat I F5	Eutelsat	1988	K3/K4	LP
23.8 E	±0.1°	DFS-3	Bundespost Germany	1992	K3-4/Ka	LP
25.7 E	±3.17°	Eutelsat I F1	Eutelsat	1983	K2/K3	CP/LP
25.7 E	±0.1°	Eutelsat I F4	Eutelsat	1988	K2/K3	LP
28.5 E	±0.1°	DFS-2	Bundespost Germany	1990	K3-4/Ka	LP
31 E	—	Turksat 1-B	Turkey	1993	K2	CP
37.3 E	±0.1°	DFS-3	Bundespost Germany	1989	K3-4/Ka	LP
42 E	—	Turksat 1-A	Turkey	1993	K2	CP
52.8 E	±1.24°	Stat. 5/Gorizont 27	CIS	1993	C3/K5	RH
57 E	±2.36°	INTELSAT 507	INTELSAT	1983	C1/K3	CP/LP
60 E	±0.1°	INTELSAT 604	INTELSAT	1990	C2/K	CP/LP
63 E	±0.1°	INTELSAT 602	INTELSAT	1990	C2/K	CP/LP
66 E	±3.00°	INTELSAT 505	INTELSAT	1982	C1/K3	CP/LP
68 E	—	PAS-6	PanAmSat [U.S.]	1995	C/K	—
72 E	—	PAS-7	PanAmSat [U.S.]	1995	C/K	—
77.5 E	—	Asiasat 2	Asiasat [Hong Kong]	1995	C/K	LP
78.5 E	—	Thaicom A2	SCC [Thailand]	1994	C1/K	CP/LP
91.5 E	±4.47°	INTELSAT 501	INTELSAT	1981	C1/K3	CP/LP
97.8 E	±0.1°	Loutch 1	CIS	1991	K5	RH
101.5 E	—	Thaicom A1	SCC [Thailand]	1984	C1/K	CP/LP

Orbit	Inc.	Satellite	Operator/Country	Start	Bands	Pol.
69 W	±0.1°	SPACENET II	GTE Spacenet [U.S.]	1984	C1/K1	LP
71.8 W	—	Anik C1	Paracom (Argentina)	1984	K1	LP
76.2 W	—	Anik C2	Paracom (Argentina)	1983	K1	LP
77 W	*	SBS 4	Hughes [U.S.]	1984	K1	HP
81 W	±0.1°	Satcom K2	GE Americom [U.S.]	1986	K1	LP
85 W	±0.1°	Satcom K1	GE Americom [U.S.]	1986	K1	LP
85 W	—	Satcom H1	GE Americom [U.S.]	1995	C1/K1	LP
87 W	±0.1°	SPACENET III	GTE Spacenet [U.S.]	1988	C1/K1	LP
89 W	—	Telstar 402	AT&T [U.S.]	1994	C1/K1	LP
91.1 W	±0.1°	Galaxy VII-H	Hughes [U.S.]	1992	C1/K1	LP
93 W	±4.78°	GSTAR III	GTE [U.S.]	1988	K1	LP
95 W	±1.36°	SBS 3	Comsat [U.S.]	1982	K1	HP
97 W	±4.56°	SBS 2	MCI [U.S.]	1982	K1	LP
97 W	—	Telstar 401	AT&T [U.S.]	1993	C1/K1	LP
99 W	—	Galaxy IV-H	Hughes [U.S.]	1993	C1/K1	LP
99.1 W	±0.1°	SBS 6	Hughes [U.S.]	1990	K1	LP
101 W	—	SPACENET IV	GTE Spacenet [U.S.]	1991	C1/K1	LP
101 W	—	DirecTv 1 & 2	Hughes/USSB [U.S.]	1994	K2	CP
103 W	±0.1°	GSTAR I	GTE [U.S.]	1985	K1	LP
105 W	±0.1	GSTAR IV	GTE [U.S.]	1990	K1	LP
106.5 W	—	M-Sat	Telesat Mobile/Canada	1994	K7/L	LP
107.3 W	±0.1°	Anik E2	Telesat Canada	1991	C1/K1	LP
111 W	±0.1°	Anik E1	Telesat Canada	1991	C1/K1	LP
113.5 W	±0.1°	Morelos F1	Mexico	1985	C1/K1	LP/CP
113.5 W	—	Solidaridas F1	Mexico	1994	C1/K1	LP
114.9 W	±1.44°	Anik C3	Telesat Canada	1982	K1	LP
116.5 W	—	Solidaridas F2	Mexico	1994	C1/K1	LP
116.7 W	±0.1°	Morelos F2	Mexico	1985	C1/K1	LP/CP
121 W	—	GSTAR I-R	GTE [U.S.]	1995	K1	LP
122.9 W	±0.1°	SBS 5	Hughes [U.S.]	1988	K1	LP
124.9 W	±0.1°	GSTAR II	GTE [U.S.]	1986	K1	LP
127.9 W	±0.1°	ASC 1	GTE Spacenet [U.S.]	1985	C1/K1	LP
157 W	—	DirecTv 3 & 4	Hughes [U.S.]	1996	K2	CP
175 W	—	Pacstar 2	Taiwan/PNG	1995	C1/K2	—
177 W	±3.55°	INTELSAT 503	INTELSAT	1981	C1/K3	CP/LP
180 E	±1.68°	INTELSAT 508	INTELSAT	1984	C1/K3	CP/LP
177 E	±0.18°	INTELSAT 511	INTELSAT	1985	C1/K3	CP/LP
174 E	±0.61°	INTELSAT 510	INTELSAT	1985	C1/K3	CP/LP
172 E	—	PacifiCom-1	TRW [U.S.]	1995	C1/K	LP
170 E	—	Unicom F1	Unicom [U.S.]	1996	C1/K	LP
168 E	—	PAS-4	PanAmSat [U.S.]	1995	C/K	—
167.5 E	—	Pacstar 1	Taiwan/PNG	1994	C1/K2	—
166 E	—	PAS-5	PanAmSat [U.S.]	1995	C/K	—
164 E	*	Optus A2	Optus[Australia]	1985	K2	LP
162 E	±0.1°	Superbird A	SCC [Japan]	1992	K2/Ka	LP
160 E	±0.1°	Optus B1	Optus [Australia]	1992	K2	LP
158 E	±0.1°	Superbird B	SCC [Japan]	1992	K2/Ka	LP
156 E	±0.1°	Optus A3	Optus [Australia]	1987	K2	LP
154 E	±0.1°	JCSat 2	Japan Sat Com	1990	K2	LP
150 E	±0.1°	JCSat 1	Japan Sat Com	1989	K2	LP
128 E	—	SAJAC-1	Sat. Japan Comm.	1994	K2	LP
124 E	—	SAJAC-2	Sat. Japan Comm.	1995	K2	LP
116 E	—	Koreasat 1 & 2	South Korea	1995	K	CP/LP
115.5 E	±0.1°	SPACENET I	China	1984	C1/K1	LP
110 E	±0.1°	BS-3A & BS-3B	Japan	1990/91	K1	RH

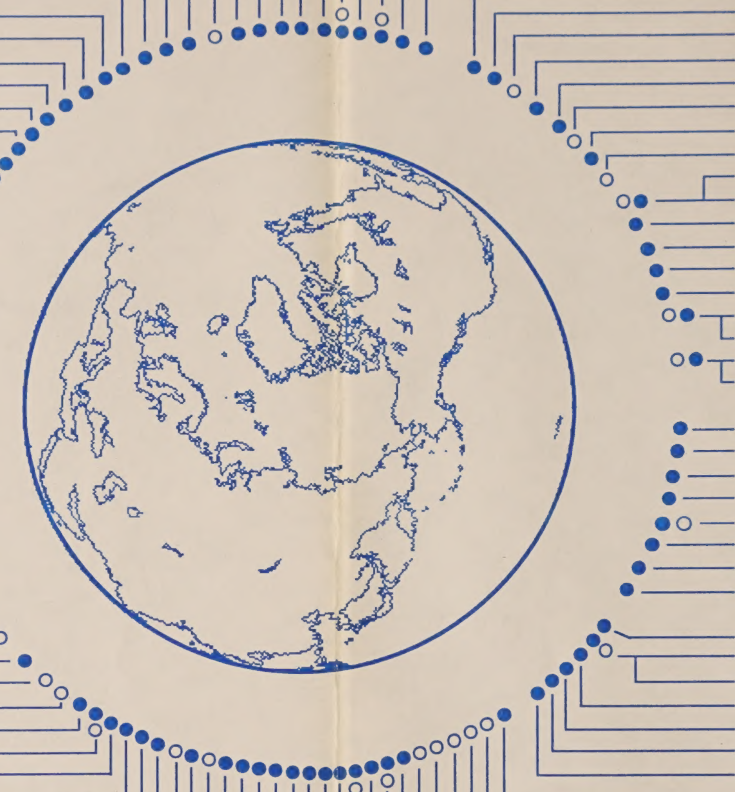
MLE INC

Post Office Box 159
Winter Beach, FL 32971
Tel: (305) 767-4687
Fax: (305) 767-6067

World Satellite A L M A N A C
Ku-Band Satellite Wall Chart

U =	700 to 730 MHz	L =	1.5 to 1.65 GHz	S =	2.5 to 2.6 GHz	C1 =	3.7 to 4.2 GHz
C2 =	3.65 to 4.2 GHz	C3 =	3.65 to 3.95 GHz	C4 =	3.4 to 3.675 GHz	C5 =	4.160 to 4.198 GHz
K1 =	11.7 to 12. 2 GHz	K2 =	12.2 to 12.7 GHz	K3 =	10.95 to 11.7 GHz	K4 =	12.5 to 12.75 GHz
K5 =	11.52 to 11.56 GHz	K6 =	11.7 to 12.5 GHz	K7 =	10.75 to 10.95 GHz	K8 =	11.7 to 11.9 GHz
Ka =	19.1 to 20.2 GHz	CP =	Circular Polarization	RH =	Right Hand Circular	LH =	Left Hand Circular
LP =	Horizontal/Vertical	VP =	Vertical only	HP =	Horizontal only	* =	Inclined Orbit

Orbit	Inc.	Satellite Name	Operator/Country	Date	Bands	Pol.
55.5 W	± 2.22°	Inmarsat II F4	Inmarsat	1992	C5/L	LP
53 W	±0.1°	INTELSAT 513	INTELSAT	1988	C1/K1–4	CP/LP
50 W	±2.01°	INTELSAT 506	INTELSAT	1983	C1/K3	CP/LP
45.5 W	±0.1°	PAS-1	PanAmSat [U.S.]	1988	C1/K1	LP
43 W	—	PAS-2	PanAmSat [U.S.]	1993	C1/K1	LP
41 W	±0.1°	TDRS-4	Columbia [U.S.]	1990	C1/K	LP
34.5 W	±0.1°	INTELSAT 603	INTELSAT	1992	C2/K	CP/LP
31.5 W	±3.56°	INTELSAT 504	INTELSAT	1982	C1/K3	CP/LP
27.5 W	±0.1°	INTELSAT 601	INTELSAT	1992	C2/K	CP/LP
24.5 W	±0.1°	INTELSAT 605	INTELSAT	1991	C2/K	CP/LP
25.1 W	±2.03°	Stat. 8/Raduga 23	CIS	1989	C3	RH
21.5 W	±3.92°	INTELSAT 502	INTELSAT	1980	C1/K3	CP/LP
18 W	±0.1°	INTELSAT 515	INTELSAT	1989	C1/K3–4	CP/LP
14 W	±0.88°	Stat. 4/Gorizont 20	CIS/Intersputnik	1990	C3/K5	RH
11 W	±1.99°	Stat. 11/Gorizont 26	CIS	1992	C3/K5	RH
8 W	±0.1°	Telecom II-A	France	1992	C1/K4	LH/LP
5 W	±0.1°	Telecom II-B	France	1992	C1/K4	LH/LP
1 W	±0.1°	INTELSAT 512	INTELSAT	1985	C1/K3	CP/LP
3 E	±0.1°	Telecom I-C	France	1988	C1/K3	LH/L
15 E	—	Amos 1 & 2	Israel	1995	C1/K3	LP
19 E	*	Anik D2	Arab Sat. Org.	1984	C1	LP
26 E	—	Arabsat II	Arab Sat. Org.	1996	C1/K/S	CP/LP
31.2 E	±0.1°	Arabsat 1-C	Arab Sat Org.	1992	C1/S	CP
34.4 E	±4.48°	Stat. 2/Raduga 19	CIS	1986	C4	RH
40 E	±0.57°	Stat. 12/Gorizont 22	CIS	1990	C3/K5	RH
48.9 E	±0.45°	Stat. 24/Raduga 1-1	CIS	1990	C3 or C4	RH
52.8 E	±1.24°	Stat. 5/Gorizont 27	CIS	1993	C3/K5	RH
57 E	±2.36°	INTELSAT 507	INTELSAT	1983	C1/K3	CP/LP
60 E	±0.1°	INTELSAT 604	INTELSAT	1990	C2/K	CP/LP
63 E	±0.1°	INTELSAT 602	INTELSAT	1981	C2/K	CP/LP
64.4 E	±1.76°	Inmarsat II F1	Inmarsat	1990	C5/L	CP
66 E	±3.0°	INTELSAT 505	INTELSAT	1982	C1/K3	CP/LP
68 E	—	PAS-6	PanAmSat [U.S.]	1995	C/K	LP
70 E	±1.21°	Stat. 20/Raduga 25	CIS	1990	C4	RH
70 E	—	Unicom F2	Unicom [U.S.]	1997	C1/K	LP
72 E	—	PAS-7	PanAmSat [U.S.]	1995	C1/K	LP
74 E	±0.1°	Insat II-A	ISRO [India]	1992	C1/S	LP
77.5 E	—	Asiasat 2	Asiasat [Hong Kong]	1995	C1/K	LP
78.5 E	—	Thaicom A2	SCC [Thailand]	1994	C1/K	LP
80.3 E	±0.35°	Stat. 13/Gorizont 24	CIS/Intersputnik	1991	C3/K5	RH
83.1 E	±0.1°	Insat 1-D/II-C	ISRO [India]	1990/93	C1/S	LP
84.7 E	±0.49°	Stat.3/Raduga 26	CIS	1990	C4	RH
87.5 E	±0.1°	Chinasat 1	China	1988	C1	LP
89.7 E	±0.62°	Stat. 6/Gorizont 21	CIS	1990	C3/K5	RH
91.5 E	±4.47°	INTELSAT 501	INTELSAT	1981	C1/K3	CP/LP
93.5 E	—	Insat II-B	ISRO [India]	1993	C1/S	LP
96.8 E	*	Stat. 14/Gorizont 19	CIS	1989	C3/K5	RH
101.5 E	—	Thaicom A1	SCC [Thailand]	1994	C1/K	LP
103.1 E	±0.68°	Stat. 21/Gorizont 25	CIS	1986	C3	RH
105.5 E	±0.1°	Asiasat 1	Asiasat [Hong Kong]	1989	C1	LP
107.9 E	±0.1°	Palapa B2R/C1	Telekom [Indonesia]	1990/95	C1	LP
110.7 E	±0.1°	Chinasat 2	China	1988	C1	LP
113 E	±0.1°	Palapa B2P/C2	Telekom [Indonesia]	1987/95	C1	LP
115.5 E	±0.1°	Spacenet 1	China	1984	C1/K1	LP
118 E	±0.1°	Palapa B4	Telekom [Indonesia]	1992	C1	LP



Orbit	Inc.	Satellite	Operator/Country	Start	Bands	Pol.
62.1 W	±0.1°	TDRS-6	ARC Pro. Serv. [U.S.]	1993	C1/K	LP
65 W	±0.1°	SBTS A1	Telebras/Brazil	1985	C1	LP
65 W	—	Brazilsat B1	Telebras/Brazil	1994	C1	LP
69 W	±0.1°	SPACENET II	GTE Spacenet [U.S.]	1984	C1/K1	LP
70 W	±0.1°	SBTS A2	Telebras/Brazil	1986	C1	LP
70 W	—	Brazilsat B2	Telebras/Brazil	1994	C1	LP
72 W	±0.1°	Satcom F2R	GE Americom [U.S.]	1983	C1	LP
74.1 W	±0.1°	Galaxy II	Hughes [U.S.]	1983	C1	LP
85.1 W	±0.1°	Telstar 302	AT&T [U.S.]	1984	C1	LP
87 W	±0.1°	SPACENET III	GTE Spacenet [U.S.]	1988	C1/K1	LP
89 W	—	Telstar 402	AT&T [U.S.]	1994	C1/K1	LP
91.1 W	±0.1°	Galaxy VII-H	Hughes [U.S.]	1992	C1/K1	LP
93.5 W	±0.1°	Galaxy III	Hughes [U.S.]	1984	C1	LP
95 W	—	Galaxy III-H	Hughes [U.S.]	1994	C1/K1	LP
96 W	±0.1°	Telstar 301	AT&T [U.S.]	1983	C1	LP
97 W	—	Telstar 401	AT&T [U.S.]	1993	C1/K1	LP
99 W	±0.1°	Galaxy VI	Hughes [U.S.]	1990	C1	LP
99 W	—	Galaxy IV-H	Hughes [U.S.]	1993	C1/K1	LP
101 W	—	SPACENET IV	GTE [U.S.]	1991	C1/K1	LP
106 W	*	Marisat F1	Comsat [U.S.]	1976	C5/L	LP
107.3 W	±0.1°	Anik E2	Telesat Canada	1991	C1/K1	LP
111 W	±0.1°	Anik E1	Telesat Canada	1991	C1/K1	LP
113.5 W	±0.1°	Morelos F1	Mexico	1985	C1/K1	LP/CP
113.5 W	—	Solidaridas F1	Mexico	1994	C1/K1/L	LP
116.7 W	±0.1°	Morelos F2	Mexico	1985	C1/K1	LP/CP
116.5 W	—	Solidaridas F2	Mexico	1994	C1/K1/L	LP
123 W	±0.1°	Telstar 303	AT&T [U.S.]	1985	C1	LP
125.1 W	±0.1°	Galaxy V	Hughes [U.S.]	1992	C1	LP
127.9 W	±0.1°	ASC 1	GTE Spacenet [U.S.]	1985	C1/K1	LP
130.8 W	±0.1°	Satcom C-3	GE Americom [U.S.]	1992	C1	LP
133 W	±0.1°	Galaxy I/1-R	Hughes [U.S.]	1983/94	C1	LP
134.9 W	±0.1°	Satcom C-4	GE Americom [U.S.]	1992	C1	LP
137.1 W	±0.1°	Satcom C-1	GE Americom [U.S.]	1990	C1	LP
139 W	±0.1°	Aurora II	Alascom [U.S.]	1991	C1	LP
170 W	±3.39°	Stat. 10/Raduga 21	CIS	1987	C3	RH
174.5 W	±0.1°	TDRS-5	Columbia [U.S.]	1991	C1/K	HP
175 W	—	Pacstar 2	Taiwan/PNG	1994	C1/K2	LP
177 W	±3.55°	INTELSAT 503	INTELSAT	1981	C1/K3	CP/LP
180 E	±1.68°	INTELSAT 508	INTELSAT	1984	C1/K3	CP/LP
178 E	±1.85°	Inmarsat II F3	Inmarsat	1992	C/L	LP
177 E	±0.18°	INTELSAT 511	INTELSAT	1985	C1/K3	CP/LP
174 E	±0.1°	INTELSAT 510	INTELSAT	1985	C1/K3	CP/LP
172 E	—	PacifiCom-1	TRW [U.S.]	1995	C1/K	LP
170 E	—	Unicom F1	Unicom Corp. [U.S.]	1996	C1/K	LP
168 E	—	PAS-4	PanAmSat [U.S.]	1995	C/K	LP
167.5 E	—	Pacstar F1	Taiwan/PNG	1994	C1/K2	LP
166 E	—	PAS-5	PanAmSat [U.S.]	1995	C/K	LP
140.2 E	±1.74°	Stat. 7/Gorizont 18	CIS	1989	C3/K5	RH
136 E	±0.1°	CS-3B/NSTAR-B	NTT [Japan]	1988/95	C1/Ka	CP
133.9 E	±2.54°	Palapa Pacific-1	Telekom [Indonesia]	1983	C1	LP
132 E	±0.1°	CS-3A/NSTAR-A	NTT [Japan]	1988/94	C1/Ka	CP
128.6 E	±0.55°	Raduga 27	CIS	1991	C3	RH

Post Office Box 159
Winter Beach, FL 32971
Tel: (305) 767-4687
Fax: (305) 767-6067

World Satellite ALMANAC
C-Band Satellite Wall Chart

U =	700 to 730 MHz	L =	1.5 to 1.65 GHz	S =	2.5 to 2.6 GHz	C1 =	3.7 to 4.2 GHz
C2 =	3.65 to 4.2 GHz	C3 =	3.65 to 3.95 GHz	C4 =	3.4 to 3.675 GHz	C5 =	4.160 to 4.198 GHz
K1 =	11.7 to 12. 2 GHz	K2 =	12.2 to 12.7 GHz	K3 =	10.95 to 11.7 GHz	K4 =	12.5 to 12.75 GHz
K5 =	11.52 to 11.56 GHz	K6 =	11.7 to 12.5 GHz	K7 =	10.75 to 10.95 GHz	K8 =	11.7 to 11.9 GHz
Ka =	19.1 to 20.2 GHz	CP =	Circular Polarization	RH =	Right Hand Circular	LH =	Left Hand Circular
LP =	Horizontal/Vertical	VP =	Vertical only	HP =	Horizontal only	* =	Inclined Orbit